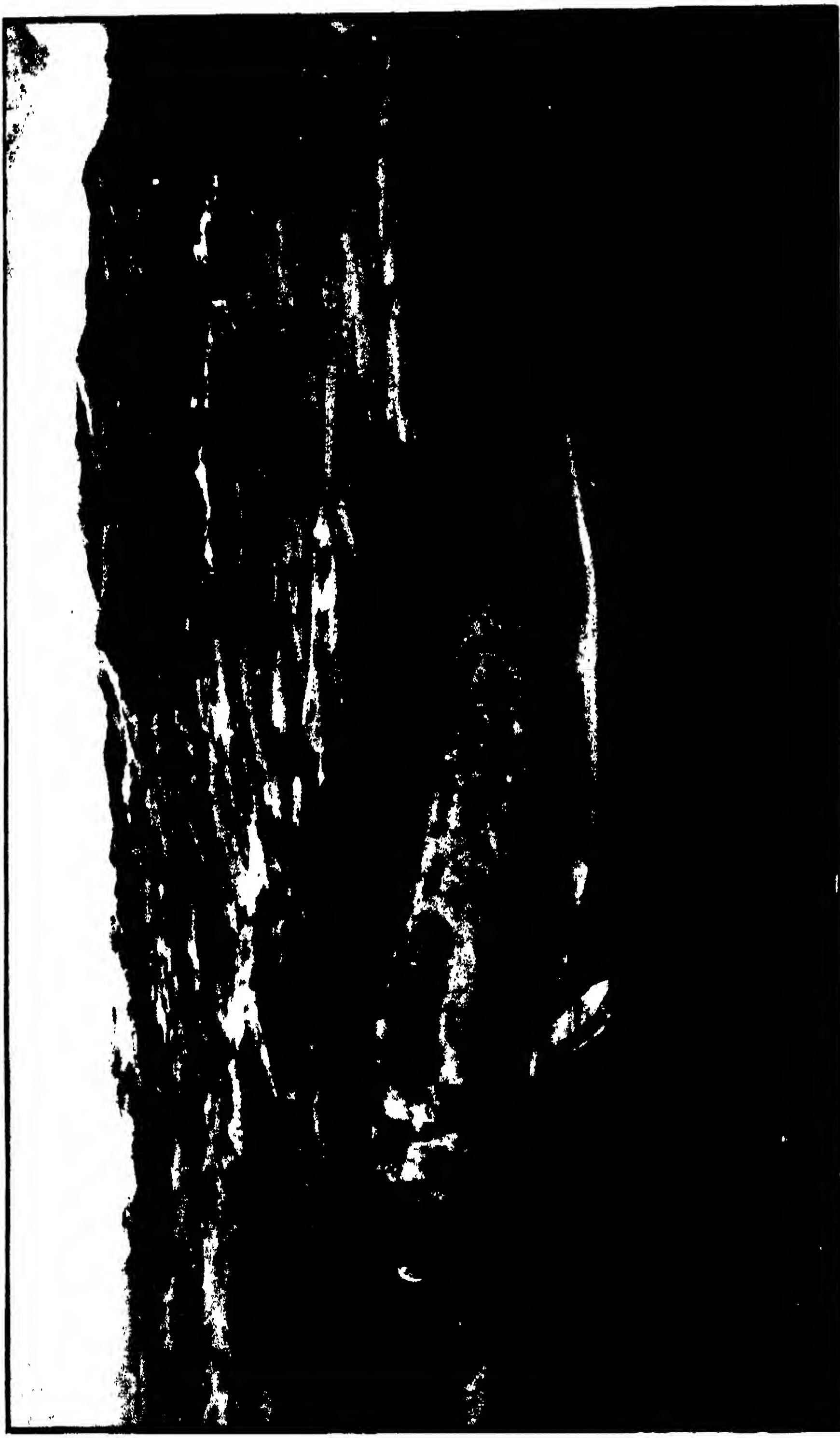
The Natural History of Animals

E04789



THE COMMON MACKEREL (*Scomber vernalis*)

This well-known fish inhabits the Atlantic and Mediterranean, and approaches our shores in large shoals in pursuit of herrings. It is remarkable for beautiful coloration, and also for its graceful shape, which is an adaptation to rapid swimming, offering but little resistance to the surrounding water. The symmetrical, deeply-forked tail serves as a propeller of unusual power, and the lateral muscles are of a reddish colour, owing to the abundant blood-supply, which is associated with the power of prolonged and swift movement. The upper and lower rows of "finlets" on the hinder part of the body are characteristic.

The Natural History of Animals

The Animal Life of the World in its various Aspects and Relations

BY

J. R. AINSWORTH DAVIS, M.A.

TRINITY COLLEGE, CAMBRIDGE
PROFESSOR IN THE UNIVERSITY OF WALES, AND PROFESSOR OF ZOOLOGY AND GEOLOGY IN UNIVERSITY COLLEGE, ABERYSTWYTH

HALF-VOL. V

LONDON
THE GRESHAM PUBLISHING COMPANY
34 SOUTHAMPTON STREET, STRAND

CONTENTS

HALF-VOL. V

ANIMAL MOVEMENT

CHAPTER XL.—ANIMAL MOVEMENT—FIRST PRINCIPLES

CHAPTER XLI.—MUSCULAR LOCOMOTION—SWIMMING OF LOWER INVERTEBRATES

CHAPTER XLII.—MUSCULAR LOCOMOTION—SWIMMING OF HIGHER INVERTEBRATES

SWIMMING MOLLUSCS (MOLLUSCA)

CHAPTER XLIII.—MUSCULAR LOCOMOTION—PRIMITIVE VERTEBRATES AND FISHES AS SWIMMERS

CHAPTER XLIV.—MUSCULAR LOCOMOTION—AMPHIBIANS, REPTILES, BIRDS, AND MAMMALS AS SWIMMERS

SURFACE-SWIMMING BIRDS

BIRDS WHICH SWIM UNDER WATER AND DIVE

MAMMALS (MAMMALIA) AS SWIMMERS

CHAPTER XLV.—MUSCULAR LOCOMOTION—CREEPING ANIMALS

CHAPTER XLVI.—MUSCULAR LOCOMOTION—WALKING, RUNNING, &c.

MAMMALS (MAMMALIA) AS WALKERS AND RUNNERS

CHAPTER L.—MUSCULAR LOCOMOTION—CLIMBING

MAMMALS (MAMMALIA) AS CLIMBERS

LIST OF ILLUSTRATIONS

HALF-VOL. V

COLOURED PLATES

BLACK-AND-WHITE ILLUSTRATIONS

NATURAL HISTORY

ANIMAL MOVEMENT

CHAPTER XL

ANIMAL MOVEMENT—FIRST PRINCIPLES

The living substance (protoplasm) which constitutes the essential part of the bodies of animals is endowed with a number of powers which characterize life as we know it. Ability to feed and breathe are two of these, and have been considered at considerable length in preceding sections. Living substance is also *contractile*, *i.e.* it is capable of changing its shape without diminution of volume, and this is the cause of all animal movements. Such movements lead to many results, some of which have already been dealt with, and of these results one of the most interesting is locomotion, in water, on the land, and in the air. Marked powers in this respect are characteristic of average animals as compared with average plants, and their purpose is sufficiently obvious. It is clear, for instance, that since animals require food of complex character, they must, as a rule, either move about in search of it, or else be possessed of arrangements whereby it is brought to them. The former state of things is the more usual, but in either case the contractile power of living substance is the primary motive power, and it may be desirable in the first instance to inquire more narrowly into the nature of this power. Most of the space in this section will, however, be given to the different kinds of Animal Locomotion.

As briefly explained in volume i, pp. 48, 49, there are three kinds of movement exemplified among animals, *i.e.* (1) Amœboid

Movement, (2) Ciliary Movement, and (3) Muscular Movement, the first of these being the most primitive, and the last the most complex.

AMŒBOID MOVEMENT

This derives its name from the Proteus Animalcule or Amœba (see vol. i, p. 488), one of the simplest of existing animals, consisting as it does of a mere speck of comparatively pure living matter or protoplasm, devoid of any firm investment. It is, in fact, a mere unit-mass of such material, technically known as a *cell*. Constant change of shape here takes place (fig. 577), the result being that the protoplasm is thrust out into bluntish lobes termed *pseudopods*, by means of which the animal is able to crawl along, flowing after them, as it were, as they are protruded in a given direction. The pseudopods also serve, as we have elsewhere seen (vol. ii, p. 268), to engulf small plants and other bodies which are used as food. They are not in any sense permanent structures, but can be, and are, withdrawn from time to time, so as to be merged in the general substance of the body. We may take amœboid movement also to include stream-like flowings within the body of the Amœba, by which the food is carried round and round during the process of digestion. Movements of the kind are also clearly visible in the bodies of higher Animalcules, such as the Bell-Animalcule (*Vorticella*), where the presence of a firm external membrane or cuticle prevents pseudopods from being formed (see fig. 577).

The leading distinction between Animalcules (*Protozoa*) and animals higher in the scale (*Metazoa*) is that the former are unit-masses of protoplasm, *i.e.* are *single-celled* (unicellular), while the latter are more or less complex aggregates of such units, *i.e.* are *many-celled* (multicellular). It is the rule that some of the cells which make up the bodies of animals other than Animalcules should retain their powers of amœboid movement, as manifested not only by streamings within their substance, but also by the thrusting out of pseudopods. In the Freshwater Polype (*Hydra*), for example, a creature which is practically a living stomach with a double wall (see vol. i, p. 465), the digestive cavity is lined by large cells which possess the power of protruding pseudopods for the purpose of seizing food. And many other cases of the same kind might be mentioned.

Among the cells which build up the bodies of such forms as Worms, Star-Fishes, Arthropods, Molluscs, and Backboned Animals, are many which may be called "wandering cells", since they are not connected together like the constituents of muscle, nerve, &c., but move about by means of pseudopods. These abound in the circulatory fluids, and to them belong the colourless corpuscles of human blood and lymph (fig. 575), though it must not be supposed that they exist in the blood of all animals. An earth-worm, for example, possesses an elaborate system of blood-vessels, but there are no colourless corpuscles in the contained fluid, though such are abundantly present in the lymph which fills the large space (body-cavity) between the internal organs and the wall of the body. Plenty of wandering cells are also found in the "jelly" of jelly-fishes and the soft substance of sponges, though in these cases blood-system and lymph-system are both absent.

Fig. 575.—Colourless Corpuscle, greatly magnified, showing successive changes of shape, and protrusion of pseudopods

It is very interesting to find that the higher (compared to animalcules) animals of which mention has just been made, though they no longer use amœboid movement as a means of locomotion, employ it for other and very important purposes. Their wandering cells resemble amœba not only in structure and way of moving, but also in their method of feeding, by taking in solid particles bodily. So great is their independence that under suitable treatment they retain their vitality a long time after being removed from the body to which they belong, and can even be fed.

To do full justice to these curiously independent wandering cells would require a very considerable space, and it is only possible here to indicate some of their spheres of usefulness. They have metaphorically been called the scavengers, police, and defensive army of the body, and all these terms are more than justifiable. A remarkable instance of their scavenging function is exemplified by Star-Fishes. Although these animals possess specialized breathing organs, they are badly off as regards structures which perform the work of kidneys, *i.e.* get rid of nitrogenous waste products. The wandering cells make good this deficiency, for they take up granules consisting of this kind of waste, and

then make their way to the exterior through thin places existing between the hard limy deposits in the wall of the body. Whether or no they get rid of the waste and then re-enter the body is not known, but such an occurrence is not impossible.

Wandering cells play an important part during development, when the various organs of the body are being, as it were, modelled out of plastic material, and also in cases where more or less remodelling is required in the course of the life-history. Of the latter phenomenon a good instance is afforded by the way a tadpole's tail disappears, as a part of the modifications necessary to produce a fully-formed frog. Many persons suppose that the tail simply drops off, but this is not so, for the material of which it is made up is too valuable to be thrown away. What really happens is that its substance gradually breaks down and is carried by wandering cells into the main body, there to be utilized for other purposes.

But by far the most interesting use of such cells is that of combating disease-germs which make their way into the system, eating them up amœba fashion. Were it not for the constant activity of these minute guardians of the body, infectious diseases would be able to do infinitely more mischief than is the case at present. And it is quite likely that the protection from disease afforded by inoculation may be due to the fact that this process has, so to speak, trained the wandering cells of the body to deal with some particular sort of invader.

CILIARY MOVEMENT

It is clear that only a naked mass of living matter (protoplasm) is able to protrude pseudopods, and in the case of cells covered by a firm membrane they are often replaced by the delicate protoplasmic threads known as *cilia* and *flagella* (fig. 576). These are protruded through little holes in the membrane covering the cell to which they belong, and in typical cases differ from pseudopods in being permanent structures which cannot be pushed out and again withdrawn at pleasure. In some animalcules we find slender thread-like pseudopods, which may be regarded as a stage in the evolution of the more specialized structures now under consideration. It may be as well to note here that a *flagellum* is a comparatively long thread of which only one, two, or at most

a few, are borne on the same cell. It is capable of complex lashing movements. A *cilium*, on the other hand, is a relatively short thread, of which large numbers project from a single cell, and which is only capable of alternate bending and straightening. But in either case the result is something more definite than amœboid movement, as might be expected from the fact that the motile structures are of higher grade than pseudopods.

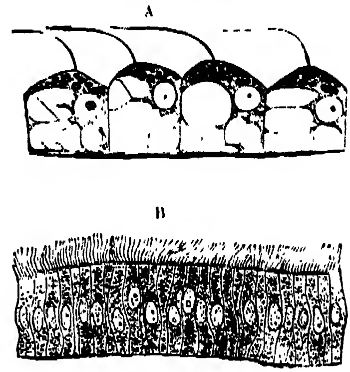


Fig. 576.
A, Four flagellated cells. B, Ciliated epithelium. Sections (greatly enlarged)

CILIA.—It is a very remarkable fact that numerous cilia are able to work together for a given end, numerous examples of this being furnished by different animalcules, one group of these being called "Ciliata", because they are provided with structures of the kind.

Ciliary action, for example, is quite competent to serve as a means of swimming, as seen in the Slipper-Animalcule (*Paramœcium*) and many other forms (fig. 577 C). In such animals the mouth is placed in a depression lined by special cilia, the working of which sets up currents by means of which food is procured. In fixed forms the latter is the chief use of the cilia which are present, the currents of water produced also bringing a supply of fresh oxygen for breathing purposes, while there are counter-currents which carry away the various products of waste. An excellent instance of this is presented by the Bell-Animalcule (*Vorticella*), in which the body is in the shape of a rounded cone, tapering at its narrow end into a stalk that is fixed to a plant or other firm body (fig. 577 B). The broad end is furnished with a short spiral of cilia, by which the necessary currents are set up. Bell-Animalcules may also be seen in which the stalk is absent, and in this case the cilia are the swimming organs. Some of these free individuals are the same in structure as the stalked ones, but others are both smaller and simpler, except that they possess a special band of cilia round the narrow end of the body, and this is related to the method of locomotion.

Cilia may also be used for creeping, as, for instance, in one or two small flattened Comb-Jellies (*Cœloplana* and *Ctenoplana*),

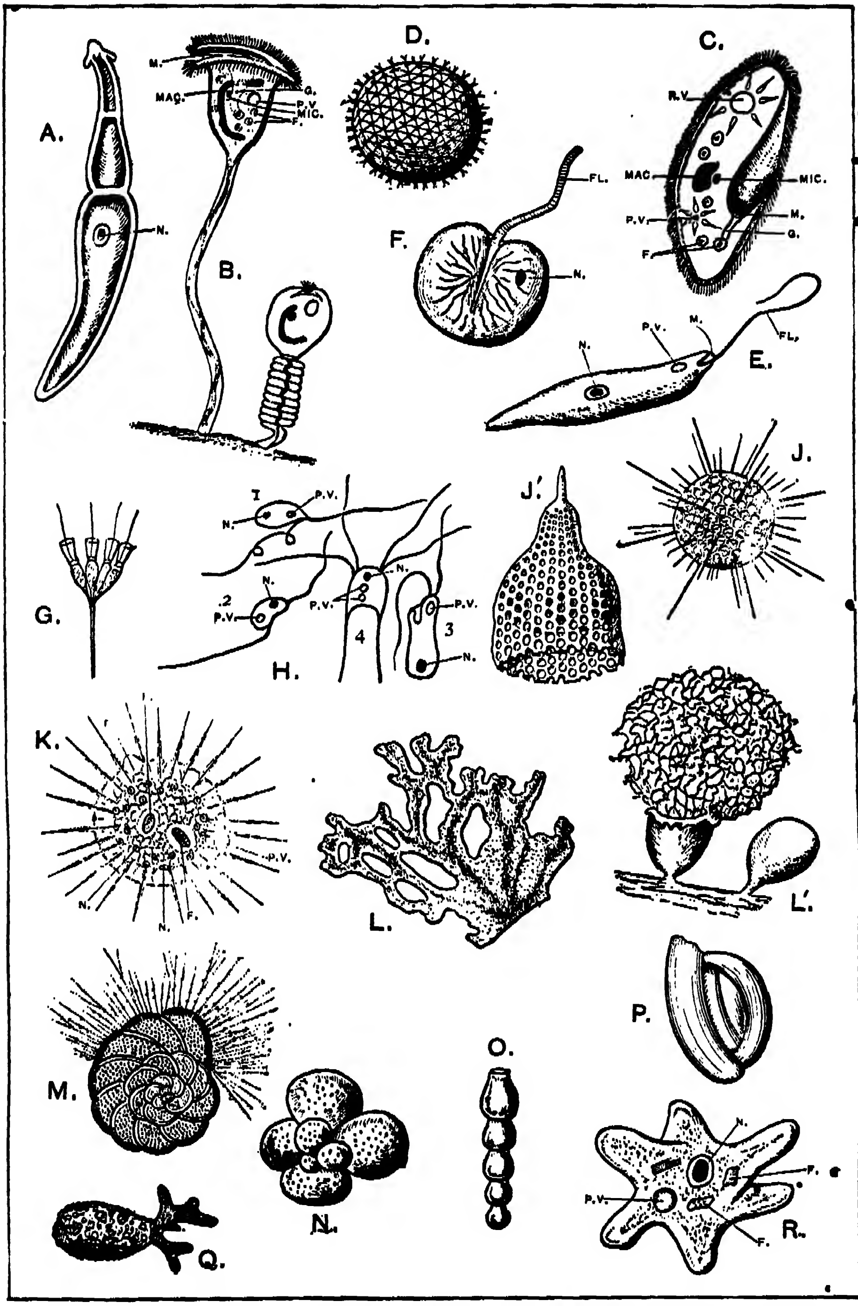


Fig. 577.—Protozoa, enlarged to various scales. Reference letters:—F, Food; FL., flagellum; G, gullet; M, mouth; MAC., macronucleus; MIC., micronucleus; N, nucleus; P.V., pulsating vacuole

A, Cockroach Gregarine (*Clepsidrina blattarum*). B, Bell-Animalcule (*Vorticella*), extended and retracted. C, Slipper-Animalcule (*Paramæcium*). D, Volvox. E, Euglena. F, Noctiluca. G, Codonocladium. H, Monads: 1 and 2, Springing Monad (*Heteromita*); 3, *Chilomonas*; 4, *Hexamita*. J and J', Skeletons of Radiolaria (*Heliosphæra* and *Eucyrtidium*). K, A Sun-Animalcule (*Actinosphærium*). L and L', Small piece of a Mycetozoon and two capsules (one ruptured) of same. M, A Foraminifer (*Rotalia*), with protruded threads of protoplasm. N, O, P, Shells of Foraminifera (*Globigerina*, *Nodosaria*, and *Miliola*). Q, A shell-bearing Rhizopod (*Difflugia*), allied to Amœba. R, Proteus Animalcule (*Amœba*).

and in the Planarian Worms (*Turbellaria*) (fig. 578). These worms are mostly of flattened shape, and clothed with a uniform covering of short cilia, by which a sort of gliding movement is effected, greatly aided by the fact that the skin secretes and pours out a kind of slime. Land Planarians, although they live in damp places, would have a difficulty in moving by means of their cilia were it not for the presence of this secretion.

Fig. 578.—A Freshwater Planarian Worm (*Planaria gonocephala*), enlarged

Locomotion by means of cilia is of uncommon occurrence in the adults of animals higher in the scale than Planarian Worms, but is abundantly exemplified by aquatic embryos of such animals,

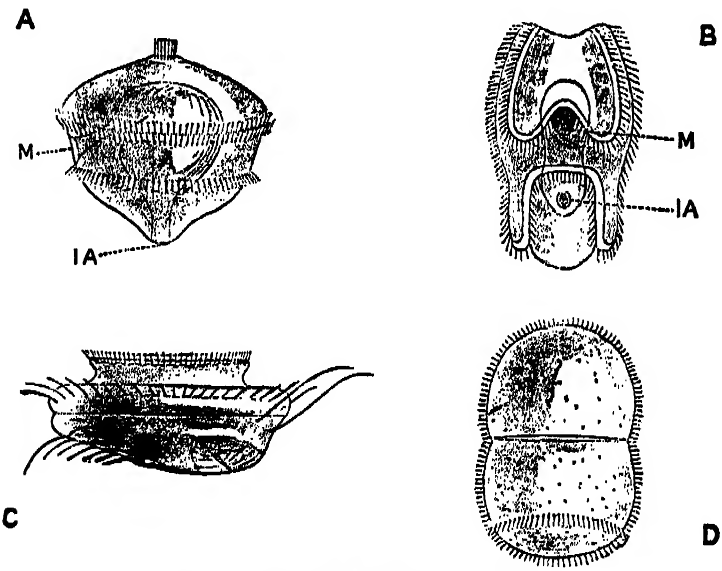


Fig. 579.—Ciliated Larvæ, enlarged to various scales
A, Annelid. B, Sea-Cucumber. C, Moss-Polype. D, Acorn-headed Worm (very young stage)
M, Mouth. I A, Intestinal aperture.

especially when these are *larvæ*, which, though they lead an independent existence, are very different from the adults into which they later on develop. Among larvæ which swim in this fashion are those of marine Annelids (*Trochospheres*), Echinoderms, Moss-Polypes, and the Acorn-headed Worm (*Balanoglossus*) (fig. 579).

In the adult animals of certain groups higher than Protozoa ciliary currents play a very important part in procuring food,

bringing fresh supplies of oxygen, and carrying away the various kinds of waste. Mention may here be especially made of Sea-Lilies and Feather-Stars (*Crinoidea*), Moss-Polypes (*Polyzoa*), Lamp-Shells (*Brachiopoda*), Bivalve Molluscs (*Lamellibranchia*), Sea-Squirts (*Urochorda*), and the Lancelet (*Amphioxus*). A curious negative character of the great phylum of Arthropods is found in the complete absence of cilia.

Cilia are also of use in helping to carry onwards the contents of various tubular structures in animals of the most diverse nature. We find them lining the digestive tube of certain low Annelids, and they clothe the mouth-cavity and part of the gullet in Frogs. They are also commonly present in excretory tubules, whether these open independently to the exterior, as in an earth-worm, or form part of a complicated kidney, as in a frog. Even in Man himself a use is found for these structures, for they are present on the lining of the air-passages, working together in such a manner that particles of dust or other foreign bodies are gradually carried out to the exterior.

FLAGELLA (figs. 576 and 577).—These structures are characteristic of one important group of Animalcules, called on this account the *Flagellata* (see vol. i, p. 494). In free-swimming members of this group locomotion is effected by a flagellum, which drags along its owner after it, much as an expert swimmer is able to propel himself by means of one arm while his legs and other arm remain passive. The life-history of some other Animalcules (*Mycetozoa*) exhibits a flagellate stage, which swims in a similar way.

Sponges may be taken as an example of animals higher than Animalcules in which flagella play an important part in the life processes. For a Sponge is traversed by more or less elaborate canals, which are partly lined by flagellate cells. The movements of the flagella which these bear set up currents that answer the same purposes as the ciliary currents of the forms mentioned above.

MUSCULAR MOVEMENT

Strands of living matter are specialized into muscle-fibres in all the groups of animals, from Animalcules upwards. A good and simple example is afforded by the Bell-Animalcule (*Vorti-*

cella), one end of which is fixed by a hollow elastic stalk to some firm body. Running through the stalk, and forming a specialized part of the single cell of which the animal consists, is a muscle-fibre, which takes a wavy course from side to side (fig. 577 B). When it contracts, *i.e.* shortens and broadens, the stalk is thrown into a spiral, and the animal is able in this way to draw itself back from any object that threatens danger. When the fibre ceases to contract, the elasticity of the stalk straightens it out again.

All animals except Animalcules possess more or less complex bodies made up of numerous unit-masses of living substance, or *cells*; whereas an Animalcule consists of but a single cell, though the parts of this may be extremely specialized, *e.g.* a Bell-Animalcule possesses a muscle-fibre, a short spiral of cilia, a mouth, and a gullet. In other words, there is a *division of physiological labour* between the parts of the single cell in such a case, and these parts are more or less different from one another, *i.e.* are *differentiated.* But it is clear that when an animal is made up of many cells the possibilities of division of labour, with accompanying differentiation, are very great.

The amount of specialization in the way indicated is the real criterion as to whether a given kind of animal is "higher" or "lower" in the scale than some other sort of animal. As judged by this standard, for instance, an Insect is "higher" than a Centipede, and this again higher than Peripatus. Or we may say that an Amphibian is "lower" than a Reptile, and this again "lower" than a Mammal. Annelids are to be ranked above Zoophytes, and so on. Such comparisons are most fruitful when members of the same great animal group (*phylum*), or of a still smaller subdivision, are in question. For each group is specialized on lines of its own, being a distinct branch of the animal genealogical tree, and it would be difficult to say, for instance, whether an Insect is higher than a Cuttle-fish, or the contrary, for the two animals are adapted to a totally different set of external conditions, one being eminently marine, and the other eminently terrestrial, or indeed aerial. But we can hold with justice that a Bee is higher than a Cockroach, or that an Oyster is inferior to a Whelk.

If we consider the structure of a highly complex form, say a backboned animal, it will be found that its cells are divisible

into several groups, or *tissues*, which are modified in different ways to fit them for the work which they perform (see vol. i, pp. 468–469). There is, for instance, nerve-tissue, which correlates the activities of the animal, and by aid of sense-organs keeps it in touch with its surroundings; and there is muscular-tissue, or muscle, with which we are here specially concerned. This is the agent of the most specialized form of movement, *i.e.* muscular movement. In muscle of all kinds the component elements are more or less converted into fibres, possessing the characteristic property of contraction, which means the power of shortening and at the same time of becoming broader.

The tissues are not much specialized in the lower groups of animals, and this is especially true of muscle. In such a creature as the Freshwater Polype (*Hydra*), the body is essentially a tube of which the wall consists of an outer and an inner layer of cells. Most of these cells are drawn out into muscle-fibres, those of the outer layer taking a longitudinal direction, and those of the inner layer a transverse or rather circular direction (fig. 580). Suppose that the fibres of the outer layer contract simultaneously, the body of the animal will obviously be shortened. If now they relax, and the fibres of the inner layer contract, it is equally clear that the body will lengthen out again, at the same time becoming narrower. Upon this simple principle are to be explained many of the internal movements which are continually going on within the bodies of animals higher in the scale than Hydra and its allies.

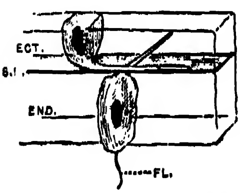


Fig. 580.—Small piece of Body-wall of Hydra (diagrammatic and greatly enlarged). ECT., Ectoderm. S.L., Supporting layer. END., Endoderm. FL., Flagellum. One ectodermic and one endodermic cell drawn, to show their muscle-fibres.

It would take up too much space, and be wearisome to the general reader, were the evolution of muscle-fibres traced throughout the animal kingdom. It will be sufficient to consider the nature and mode of action of such fibres in some of the higher forms, such as backboned animals and insects. In these cases we can distinguish between (1) unstriated muscle and (2) striated muscle, which are present in both cases, and represent two distinct grades of efficiency.

Unstriated Muscle (fig. 581).—This consists of spindle-shaped cells which are united together by their tapering ends so as to form layers in the walls of various internal organs,

including the large blood-vessels known as veins and arteries. This kind of muscle is not under the control of the will, and is therefore commonly known as "involuntary". In the intestine of a rabbit, for instance, there are two layers of such muscle, external to the mucous membrane, which forms a lining. The inner layer (or coat) is made up of fibres circularly disposed, while the fibres of the outer layer run longitudinally (compare Hydra, described above). This arrangement is adapted for squeezing the digesting food gradually onwards, for waves of contraction (peristaltic movements) pass along the layer of circular muscle, causing the cavity of the intestine to be narrowed, and thus forcing the food on. The contractions of the longitudinal layer enlarge the cavity of the tube, and at the same time pull its wall back over the food, which also assists onward progress. Regarding this Sir Michael Foster (in his *Text-book of Physiology*) says:—"A contraction of the longitudinal coat taking place in any segment of the tube would tend to draw the tube over the contents lying immediately above, or below, the segment, very much as a glove is drawn over a finger. And a succession of such contractions travelling along the tube would lead to a movement of the contents in the same direction. Were the circular coat absent a longitudinal coat might by itself possibly suffice to propel the contents along the tube."

Fig. 581.—An unstriated muscle-fibre (greatly enlarged). The dark band in the middle is the nucleus.

The wall of an artery (or vein) possesses a coat of circular muscle (fig. 582), the thickness of which depends upon the size of the vessel. It is also better developed in arteries than in veins. This coat, working under the control of the nervous system, is an important means of regulating the blood-flow. Take the case of an artery supplying a muscle with pure blood. Under average circumstances the fibres of its muscular coat are in a semi-contracted or "tonic" condition. If now the muscle supplied has need of more blood, these muscle-fibres relax, and the artery consequently enlarges. If, however, *less* blood is required, the muscle-fibres contract more strongly, and the size of the artery

Fig. 582.—Structure of small Artery (enlarged) *aa*, Lining membrane; *bb*, layer of muscle-fibres running circularly (nuclei shown in black); *cc*, external fibrous coat with nuclei.

is correspondingly diminished. It may be well to add that the arteries also help in the propulsion of blood. Not, however, by means of the muscular coat, but by the action of an elastic layer which they contain. The contracting ventricles of the heart force blood into the arteries. Part of the force is expended in propelling the blood onwards, and part in dilating the arteries. When the ventricles of the heart cease to contract, the elasticity of the arteries comes into play, for as a result of this they become reduced to their usual size, and thus exert a squeezing action on their contents, which keeps the circulation going till the ventricles once more contract. The heart, from the nature of the case, is an intermittent pump, and were the arteries rigid the blood would be forced onwards in a series of jerks, which would be exceedingly uncomfortable, to say the least of it, and would probably be very injurious to the more delicate organs, such as the brain. The periodic swelling of an important artery in the wrist can readily be seen and felt, and is familiarly known as the "pulse". Being a result of the pumping action of the heart, it serves as an indication of whether or no that organ is working with vigour and regularity.

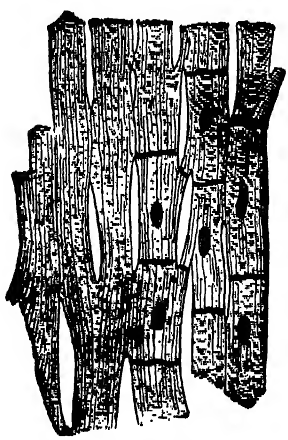


Fig. 583.—Striated Muscle of Heart (greatly enlarged)

The boundaries and nuclei of some of the cells shown on the right.

Heart Muscle (fig. 583).—The heart of a backboned animal, *e.g.* a rabbit, is chiefly made up of muscle-fibre, which, when it contracts, diminishes the contained cavities, forcing the blood onwards into the arteries, complicated valves preventing it from running back into the veins. But here the muscle-fibre is striated, though it is not so specialized as striated muscle proper, and, unlike this, it is involuntary. A little bit of it, looked at under the microscope, is seen to be made up of short broad cells united together, and markedly "striated", *i.e.* marked by numerous parallel transverse lines, and also by parallel longitudinal lines. It is not known for certain what the striations represent; perhaps they may be the expression of a specialized net-work within the cells; but, however that may be, it is a fact that striation is associated with vigorous powers of contraction, and such are required by the heart, which is essentially a force-pump.

The examples just given may serve as examples of the uses to which unstriated muscle and involuntary striated muscle are put in the bodies of higher animals, and the nature and mode of action of striated muscle proper falls next to be considered.

STRIATED MUSCLE (fig. 584).—This makes up what is popularly called the "flesh" of ordinary backboned animals, and the corresponding parts of Insects, Crustaceans, &c. Under the microscope it is seen to be composed of aggregates of slender well-striated fibres, produced by the activity of cells, though the boundaries of these are not clearly visible as in the tissue of the heart. It further differs from heart-muscle in the fact that each fibre is invested in a special membrane, and also because it is "voluntary", *i.e.* under the control of the will. Animal movements are very largely due to the action of this sort of muscle. It is the agent of the movements of breathing (see vol. i, p. 46), and is also the chief factor of muscular locomotion, though this is effected in many lower animals, such as jelly-fish and annelids, by unstriated fibres. It may also be stated generally that all the obvious movements of backboned animals and arthropods, whether they have to do with breathing and locomotion or not, result from the contractions of muscles belonging to the striated variety. This is the case, for instance, with movements of offence and defence, and those connected with securing and chewing food.

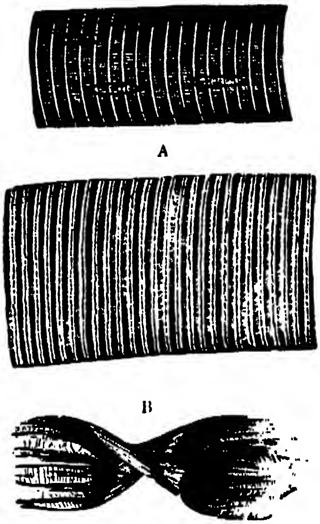


Fig. 584.—Voluntary Striated Muscle (greatly enlarged)

A, Parts of two fibres showing striations and (in upper piece) nuclei. B, Fibre torn across to show investing membrane (sarcolemma).

MUSCULAR LOCOMOTION.—The rest of the present section will deal with this alone, and before considering its different varieties a few points need elucidation. One of the most obvious facts requiring notice is that the muscular tissue of, say, a limb, is not one continuous mass, but is divided into a large number of separate parts, each of which is termed a *muscle*. In a typical case such a muscle is found to be a flat or spindle-shaped mass which has definite work to do. Walking, for example, is effected by the

combined action of a large number of muscles, some of which move the leg on the trunk, while others move the various parts of the leg on one another. The motive power is precisely the same as that by which the stalk of a Bell-Animalcule is shortened (see p. 9), *i.e.* the property of contractility, briefly termed contraction, which the fibres making up a muscle individually possess. And, as already stated, this means a shortening accompanied by a corresponding broadening, effected under the control of the nervous system, and amenable to the influence of the will. It must be premised that ordinary muscles are, when at rest, kept in a partially contracted or "tonic" condition, like the muscular coat in the wall of an artery (see p. 11). The contraction of many muscles in the human body can be observed very readily. Take, for example, the great "calf-muscle" on the back of the leg (fig. 585). Raise yourself on tiptoe, grasping one of these muscles as you do so. It will be found to swell up, or pass into a state of contraction. This is an expression of greater breadth, and careful measurement will show that there has also been a decrease in length, its two ends being brought nearer together. This is the chief principle of all muscular action, and a contracting muscle obviously exerts a pull upon the parts to which its ends are attached, and this brings about a movement, the nature of which depends upon circumstances. One important use of a skeleton is to afford surfaces and projections for the attachment of muscles, and the different parts of a skeleton are jointed together in various ways, so as to determine the character of the movement brought about by muscular action. We find, for example, in the human skeleton, that there are hinge-joints at the elbow and knee, ball-and-socket joints at the shoulder and hip, and a pivot-joint between the first and second bones of the neck (see vol. i, p. 27). The fact that the skeleton is external in such a creature as an Insect naturally leads to the muscles being attached in quite a different way from those of a backboned animal, where the skeleton is internal, but the principle of action is precisely the same.

Fig. 585.
Leg raised on tiptoe by contraction of calf-muscle, of which lower end is shown, with the tendon by which it is nto the h bone.

TENDONS.—The muscle-fibres which make up a muscle are bound together by fibrous tissue, and the muscle is covered by a

sheath of the same material. It commonly happens that a muscle is attached by one end (the *origin*) to a relatively fixed part, and by the other end (the *insertion*) to a relatively movable part. And in the case of the muscles which move the limbs the fibrous sheath passes at one or both ends into a firm inelastic cord, or *tendon*, which is attached to part of the skeleton. In this way a number of muscles can easily be fixed to a small bone (such as a finger-bone), and the tendons may be of considerable length, so that the corresponding muscles can be placed at a distance from the part moved. This is of great advantage in the case of hands and feet, for they need only contain the tendons of many of their muscles, and are thus prevented from becoming unnecessarily bulky and clumsy.

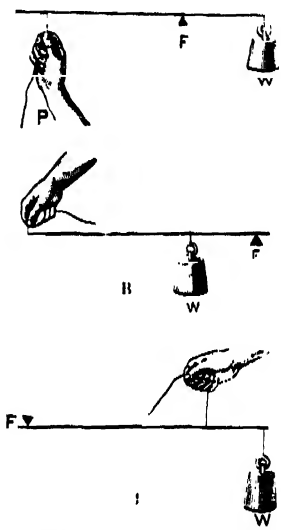


Fig. 586.—Levers of First (A), Second (B), and Third (C) Class. P, Power; F, fulcrum; W, weight or resistance

LEVERS (fig. 586).—One other mechanical principle of muscular action needs mention here, because it is of special importance with reference to locomotion. In many groups of animals swift progression is indispensable, it may be for the purpose of obtaining food, as in a tiger, or as a means of escape from enemies, as in antelopes. Each of the long bones of a limb may be regarded mechanically as a *lever*, *i.e.* a firm rod capable of being moved about a relatively fixed point known as the *fulcrum*. The work to be done may be called the *weight*, and the force doing it may be termed the *power*, this being furnished by muscular contraction in the case of animals. Levers are divisible into three classes, as follows:—(1) Levers of the *first class*, where the fulcrum is between weight and power and nearer the former, as in the case of a crowbar used to raise a block of stone. (2) Levers of the *second class*, where the fulcrum is at one end and the power at the other, the weight being between the two and nearer the fulcrum. This is exemplified by a crowbar with one end resting on the ground, and used for lifting a weight.

The value of the first and second classes of levers is that they give a mechanical advantage, enabling a relatively small power to

overcome a large resistance, though the movement is of small extent, for "what is gained in power is lost in speed". Valuable ends are served by both these varieties of lever in the body of an animal, such as a human being. When the head is bent back the first kind is exemplified, for the fulcrum is at the joint between head and backbone, the weight is that of the head, lying chiefly in front of the fulcrum, and the power is supplied by muscles attached to the back of the head. A good example of the second class is the act of raising the body on tiptoe, for in the case of either leg the fulcrum is at the front end of the foot, the power is supplied by the great calf-muscle fixed by a tendon to the heel, and the weight to be raised (that of the body) comes between.

(3) In levers of the *third class* the fulcrum is at one end, the weight at the other, and the power between. Here it may be said that "what is lost in power is gained in speed", for range and rapidity of movement result, though the power has to be relatively large. As we might expect, therefore, the animal body presents many instances of this kind of lever action. A good example is the movement by which the forearm is bent upon the upper arm. Here the fulcrum is at the elbow-joint, and the weight is that of the hand and forearm. The power is supplied by the biceps muscle on the front of the upper arm. This takes origin above in the shoulder-blade, and is inserted below into one of the bones of the forearm (radius) a little way in front of the fulcrum at the elbow-joint.

CHAPTER XLI

MUSCULAR LOCOMOTION—SWIMMING OF LOWER INVERTEBRATES

Having considered the principles of muscular action, some of which apply only to higher animals possessed of a firm skeleton, external or internal, we may next inquire into the nature of the different kinds of locomotion brought about by muscular action. In the case of many animals various forms of progression can be resorted to by the same individual, according to circumstances. A Leech can creep or swim, a Bird fly or walk, and so on. Following the plan already adopted in the earlier part of this book, it may be necessary to allude several times to the same animal or kind of animal under different subdivisions of the present section. Considering that the sea is in all probability the original home of life, it will be convenient first to consider swimming as a typical method of aquatic locomotion, though not necessarily the most primitive form of progression among marine animals. Next will come creeping upon a firm surface, whether this be covered by water or not; and after that walking, running, leaping, and the like, exemplified most familiarly by land animals, though not by them alone. Burrowing of various kinds will afford material for a sub-section, climbing for another, while flight, and simpler arrangements leading up to it, will form a fitting conclusion to this part of the book.

SWIMMING OF LOWER INVERTEBRATES

In dealing with the various kinds of swimming we are, of course, concerned with aquatic animals, and these may be either *primarily* aquatic, or *secondarily* so. Primarily aquatic forms are of purely aquatic descent, there being no reason to think that any of their ancestors ever lived on land. Jelly-Fishes, Cuttle-Fishes,

and ordinary Fishes may serve as examples. Secondarily aquatic animals, on the other hand, are those which are descended from land forms, illustrative cases being Whales and Water-insects.

Certain marine animals are able not only to swim actively, but also to drift passively along, guided by currents or blown by the wind. This reminds us of the fact that hosts of creatures chiefly or entirely depend upon the latter method of progression, to facilitate which organs of the nature of floats have been evolved in many cases. As, however, we are here concerned with muscular progression, consideration of drifting and floating organisms will be dealt with later in connection with Distribution in Space.

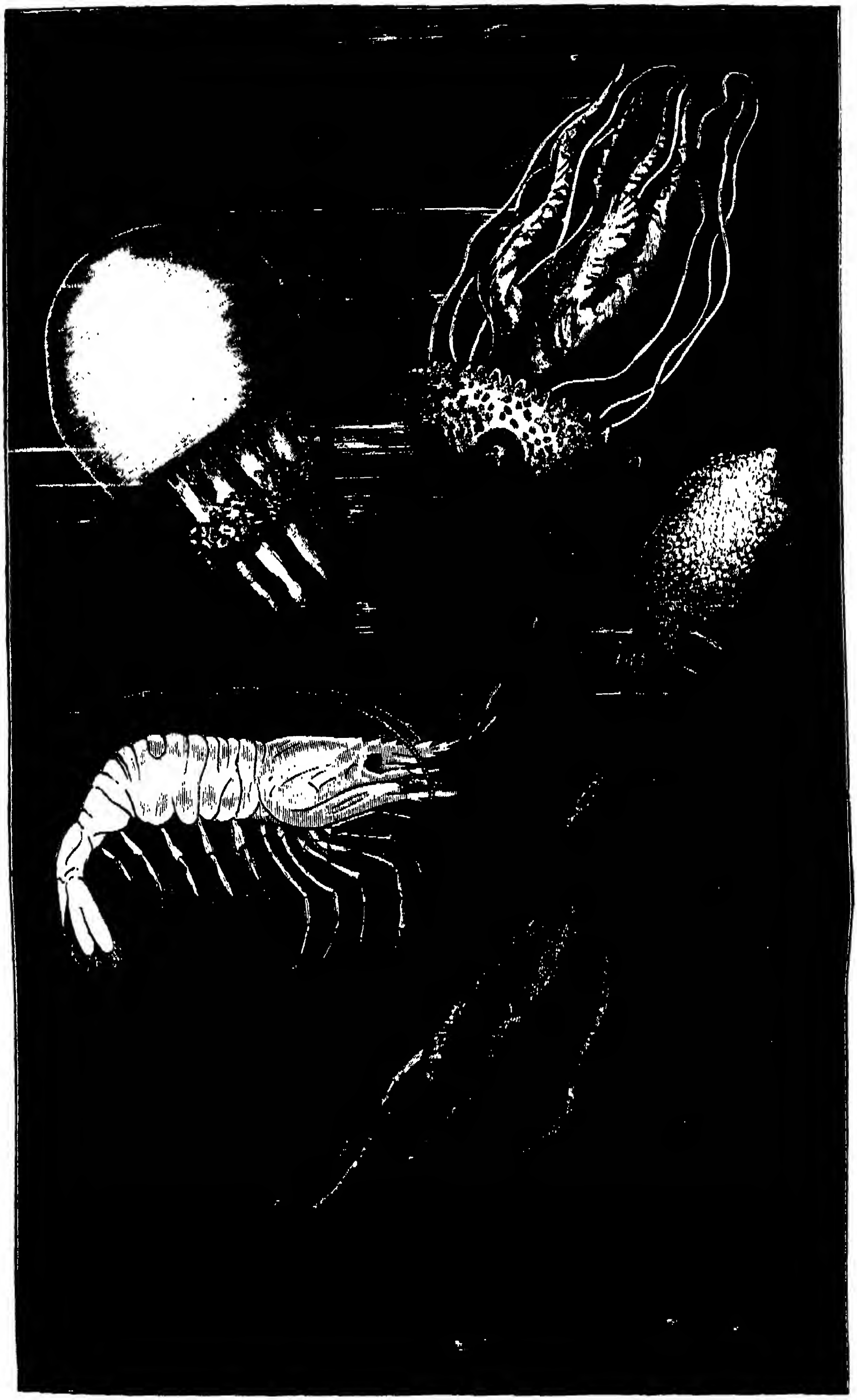
SWIMMING OF JELLY-FISH (*Hydrozoa*).—In most kinds of swimming part of the body is broadened out so as to get sufficient purchase upon the resisting medium, for the purpose of propulsion. In products of human ingenuity the same principle is necessarily followed, and may be illustrated by the broad ends of oars or the blades of a screw propeller. A simple Jelly-Fish or Medusa shows us how an extremely soft animal, devoid of any skeleton, is able to bring a sufficiently large surface to bear upon the water for the purpose of progression. Such an animal may be roughly compared to an umbrella, the mouth being placed at the end of the "handle". But the medusa differs from an umbrella in the fact that the curved part is of considerable thickness (like the top of a mushroom), owing to the presence of a large amount of jelly-like substance. This is bounded by firmer membranes both on the upper convex side and the lower concave side. The latter region, *i.e.* the inside of the umbrella, is generally called the sub-umbrella, and here are disposed muscle-fibres arranged in a circular way, parallel, that is, to the thin edge of the animal. When this layer of muscle contracts, the opening of the umbrella is thereby narrowed, and the sub-umbrella pushes against the water behind it, propelling the medusa with its convex side forwards, and in the direction of the long axis of its handle. Next follows a relaxation of the muscle-layer, causing the umbrella to expand, ready for another stroke. If you can imagine an actual umbrella possessed of the power of spontaneously opening and shutting, it is clear that it would be able to swim through the water in the same fashion as a Jelly-Fish. Medusæ vary greatly in shape and size, but they always swim in the same manner; and the movements are of very regular kind, which suggests that they

SWIMMING INVERTEBRATES

The plate illustrates typical ways of swimming as exemplified by various Invertebrates. At the top are two simple Jelly-Fish or Medusæ (3 and 4), where progression is effected by the opening and shutting of the rounded "umbrella", the under side of which possesses a thin muscular layer.

The Poulpe or Octopus (*Octopus vulgaris*, 2) swims backwards with great rapidity by forcibly ejecting the water from its mantle-cavity, in which the two gills are sheltered. Cuttle-Fishes and Squids move still more rapidly in the same way. This is an interesting example of adaptation, whereby the getting rid of water used for breathing purposes is turned to account in locomotion.

The Prawn (*Palæmon serratus*, 1), like Lobsters and Crayfishes, is also a swift backward swimmer, its movements being effected by downward strokes of the powerful tail, the end of which bears a lobed fin. It can also paddle itself along more slowly, either forwards or backwards, by means of the forked "swimmerets" situated between the walking-legs and the tail-fin.



SWIMMING INVERTEBRATES

are carried out under the direction and control of a nervous system, and this has proved to be actually the case. It is interesting to note that the muscular layer forms but an insignificant part of the animal so far as mere bulk is concerned. Romanes (in *Jelly-Fish, Star-Fish, and Sea-Urchins*) states that "This tissue constitutes the earliest appearance in the animal kingdom of true muscular fibres, and its thickness, which is pretty uniform, is nowhere greater than that of very thin paper".

In many of the free-swimming colonies to which the name of COMPOUND JELLY-FISH (*Siphonophora*) has elsewhere been applied (see vol. i, p. 481), the work of the community is shared between different members of the community, which are consequently specialized in various directions, according to their particular duties. Here we have displayed in another form the principle of division of physiological labour, which largely determines the structure of the bodies of individual animals (see p. 9). In this particular case the individuals which propel the colony are known as swimming-bells, and each of them resembles a simple medusa devoid of handle. Of such locomotor individuals there may be one, two, or many, according to the species (see vol. i, p. 481, and vol. ii, p. 162).

The remarkable forms known as COMB-JELLIES (*Ctenophora*), which have probably been evolved as an offshoot from the class (*Hydrozoa*) to which Jelly-Fishes belong, may swim in the same way, as in the case of Beroë, which is a cap-shaped creature of great voracity

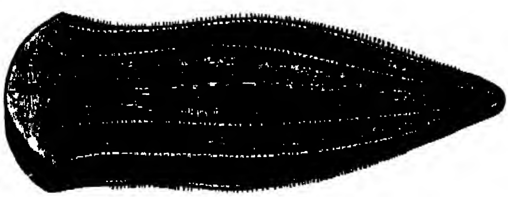


Fig. 587.—Beroë

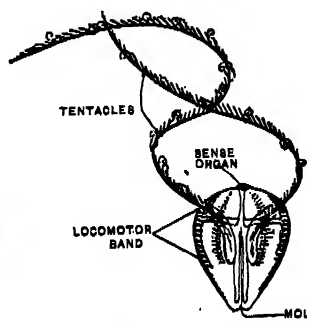


Fig. 588.—Cydippe

But the typical method of swimming which is pursued by these creatures, and which is well exemplified by the melon-shaped form Cydippe, is dependent upon the presence of a number of longitudinal bands running from one pole of the body to the other (fig. 588). Each of these bands con-

sists of a series of little swimming-plates, which can be moved to and fro under the control of the nervous system, and act like so many paddles, causing their owner to move onwards with the mouth-end at the back. It is particularly interesting to note that each little rowing-plate has been formed by the fusion of a number of those structures we have learnt to know as cilia (see p. 5). In this way mechanical efficiency is gained, for the continuous surface of the plate so constituted is able to bring a more effective stroke to bear upon the water than a series of thread-like structures. In Cydippe and many of its allies there is a long, branched fishing-line on either side of the body, which

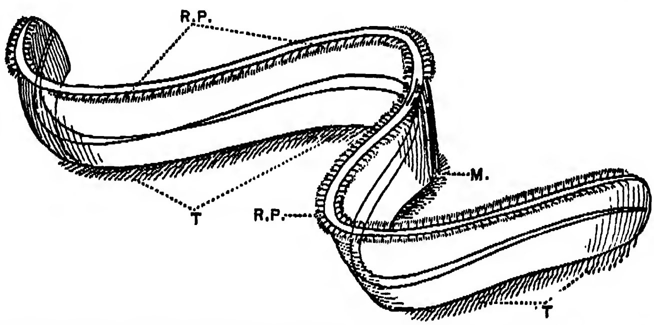


Fig. 589.—Venus's Girdle (*Cestus Veneris*), much reduced. M, Mouth; R.P. rowing-plates; T, fringe of tentacles

can either be stretched out to a considerable length or else withdrawn into a sort of pocket. These organs are probably also of use for the purpose of steering.

One of the Comb-Jellies, Venus's Girdle (*Cestus*), is shaped like a band, and is able to swim not only by means of rowing-plates, but also by undulations of the body brought about by means of muscle-fibres (fig. 589).

Swimming Planarian Worms (*Turbellaria*) and Thread-Worms (*Nemathelmia*).—Although the most characteristic mode of progression among Planarian Worms (*Turbellaria*) is creeping by means of cilia, many of them are able to swim by undulating their bodies. A more definite way of moving through the water is practised by the flattened leaf-shaped form, *Leptoplana tremellaris*, described elsewhere (vol. i, p. 446). The sides of the body are here used as paddles, being alternately bent upwards and downwards, and, being extremely flexible, are curved right over the back in the former case and right under the body in the latter. The comparatively swift movements thus brought about

are effected by thin layers of muscle-fibre in the body-wall, and the creature when swimming looks very much like a miniature copy of one of those fishes known as Skates (fig. 590).

Some of the THREAD-WORMS (*Nemathelmia*) live in water and are able to swim by means of wriggling movements of the body, produced by a peculiar muscular layer below the skin. Most persons have seen such movements in the little creature popularly known as the Vinegar-Eel (*Anguillula aceti*).

ARROW-WORMS (*Chætognatha*).—There is a small class of marine animals (*Chætognatha*) containing

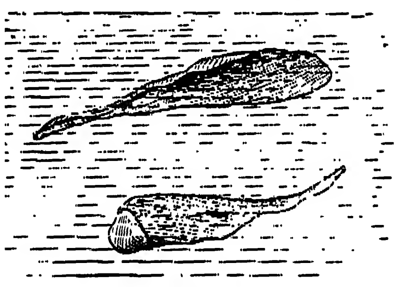


Fig. 590.—A Marine Planarian Worm (*Leptoplana tremellaris*), swimming

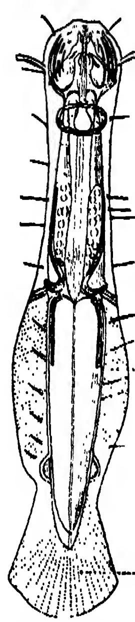


Fig. 591.—An Arrow-Worm (*Sagitta*), enlarged

certain little flattened spindle-shaped creatures called ARROW-WORMS (*Sagitta*, &c.), on account of their shape (fig. 591). They live in vast numbers in the surface-layer of the sea, and swim by bending their bodies to either side alternately. These movements are executed by the agency of a longitudinal layer of muscle-fibres in the body-wall, the part of this on one side first contracting, and then the part on the other side. These contractions are vigorous, and in correspondence with this the muscle-fibres are striated, an uncommon thing among lower forms. The powers of rapid locomotion which Arrow-Worms possess are related to their highly carnivorous habits, small crustaceans and larval fishes constituting a large part of their food. It remains to be mentioned that the tail and sides of the body are provided with fin-like expansions, supported by firm rods. These fins are not themselves swimming organs, but probably have to do with balancing and steering.

SWIMMING ANNELIDS (*Annelida*).—Annelids are segmented worms, *i.e.* the body is made up of a series of rings or segments from before backwards. They include Leeches (*Discophora*) and Bristle-Worms (*Chætopoda*), many of which are able to swim.

In a common Medicinal Leech (*Hirudo medicinalis*) swimming is effected by graceful undulations of the somewhat flattened body. The movements are brought about by three layers of muscle in the body-wall, of which the most external is circular, the middle one oblique, and the internal one longitudinal. There are also bundles of fibres running from the upper side of the body to the lower, and these by their contraction are able to flatten the body so that it presents a larger surface for the strokes taken in swimming.

The BRISTLE-WORMS (*Chætopoda*) are in the main a group of creeping, burrowing, and tube-dwelling forms; but many of the free-living marine species are capable of swimming, and some few are highly specialized for the purpose. The body-wall of one of these animals contains an external circular layer and an internal longitudinal layer of muscle-fibres, besides which bundles of muscle run to the hollow "foot-stumps", of which a series is present on each side of the body, and in which the characteristic bristles are embedded. When one of the forms, not specially adapted for the purpose, takes to swimming, it simply wriggles through the water by contraction of the muscle-layers mentioned. The most specialized swimmers in the group (species of *Tomopteris*) are surface animals living in the open sea (fig. 592). The short body is provided with enormously large flattened foot-stumps, which serve as paddles, and have lost their bristles. Two long filaments which act as sense organs project backwards from the head, and look almost like the feelers of an insect. They have possibly been produced by modification of the first pair of foot-stumps, and

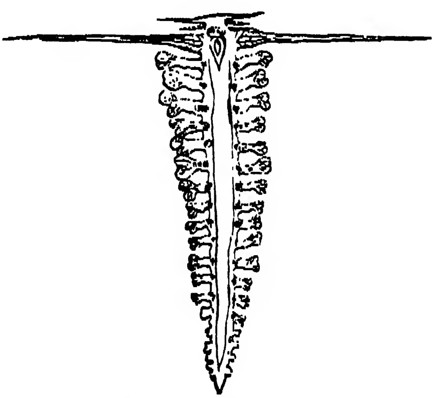


Fig. 592.—A Free-swimming Marine Bristle-Worm (*Tomopteris*)

as each is stiffened by a long slender bristle which runs right through it, they very likely help to balance the worm while it swims. Some other Bristle-Worms are specialized on the same lines as Tomopteris, but not nearly to the same extent.

SWIMMING ECHINODERMS (*Echinodermata*).—The animals of this phylum usually hatch out as active larvæ, which are often of remarkable shape, and swim by means of ciliated bands variously disposed in different cases. In the adult condition, however, most of them are specialized for creeping, and the members of one group (Sea-Lilies) are fixed. But a few forms have widened their sphere of activity by becoming adapted to the swimming habit, moving through the water somewhat after the fashion of jelly-fishes, though the parts of the body employed for the purpose are quite different. We find, for instance, that the ancient and declining group of CRINOIDS includes animals of quite different modes of life, *i.e.* Sea-Lilies and Feather-Stars. Sea-Lilies are fixed animals living in the deep sea, and broadly comparable to much-branched star-fishes fixed mouth upwards on the end of a long flexible stalk. They are the surviving remnants of a once numerous host of dominant marine creatures, the remains of which build up certain beds of limestone in the geological series. Feather-Stars, on the other hand, are exceedingly abundant all over the world, and may be regarded as sea-lilies which have given up the sedentary mode of life and abandoned their stalks (fig. 593). They are able to swim moderately well by alternately bending and straightening their branched arms, which collectively present a sufficient surface for striking on the surrounding water. But this arrangement is necessarily less efficient than in jelly-fishes, where an unbroken expansion is employed for the purpose.

Fig. 593.—A Feather-Star (*Comatula*)

The cylindrical creeping SEA-CUCUMBERS (*Holothuroidea*) would hardly be expected to swell the list of swimmers. Yet a member of the group has been discovered (*Pelagothuria*) which is much specialized in accordance with this mode of progression (fig. 594).

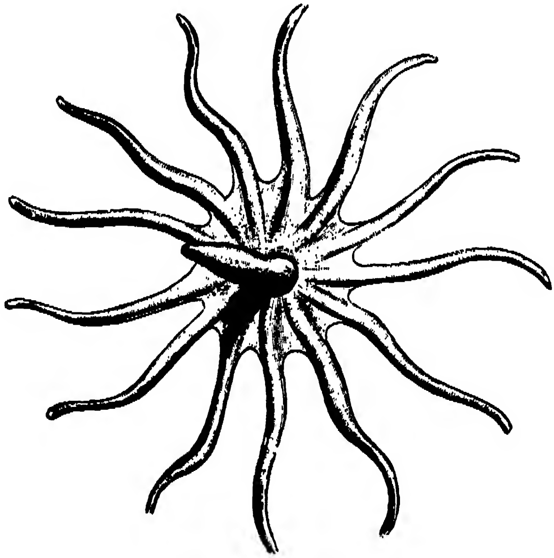


Fig. 594.—Free-swimming Sea-Cucumber (*Pelagothuria*), reduced

As in all Sea-Cucumbers the mouth is surrounded by a circlet of tentacles, which in this case are elongated, and connected together by a web, together constituting a swimming apparatus which acts much like the umbrella of a Jelly-Fish (see p. 18), and by alternately contracting and relaxing propels its owner backwards through the water. Its efficiency is increased by the fact that the body has become comparatively short.

SWIMMING NEMERTINE WORMS (*Nemertea*).—These curious unsegmented marine worms are in the main creeping forms, but some are specialized for swimming, the tail end being moved from side to side. The presence of a fin-like edge gives an increased surface. One species (*Pelagonemertes*) which lives in the open sea is short and leaf-shaped, tapering to a blunt point behind.

CHAPTER XLII

MUSCULAR LOCOMOTION—SWIMMING OF HIGHER INVERTEBRATES

In this chapter we are chiefly concerned with swimming Crustaceans, Insects, and Molluscs, which exhibit a great variety of specializations that attain the same end by different methods.

SWIMMERS AMONG LOWER CRUSTACEANS (ENTOMOSTRACA)

It is usual for lower (and much more rarely higher) crustaceans to hatch out of the egg in the condition of an active free-swimming larva known as a Nauplius (fig. 595). This has an oval body not divided into rings or segments, and provided with three pairs of jointed limbs, corresponding to the first and second feelers, and the first pair of jaws (mandibles) of the adult head. These limbs are of relatively large size, and are used as so many oars by which the animal is propelled.

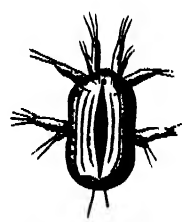


Fig. 595.—A Nauplius (enlarged)

In the adult stage of lower crustaceans (fig. 596) two other pairs of jaws (maxillæ) sprout out from the head, and a limb-bearing trunk is developed. Sometimes both pairs of feelers are used for swimming, as in the Nauplius, a case in point being that of the little MUSSEL-SHRIMPS (*Ostracoda*), in which the body is protected by a bivalve shell (fig. 596). A similar arrangement is found in the free-living members of the group of FORK-FOOTED CRUSTACEANS (*Copepoda*), of which Cyclops (fig. 596) is a common freshwater form, while many marine species are found living together in vast shoals. Here the animal can propel itself by means of the large first pair of feelers, much after the fashion of a man swimming by means of his arms alone, though the

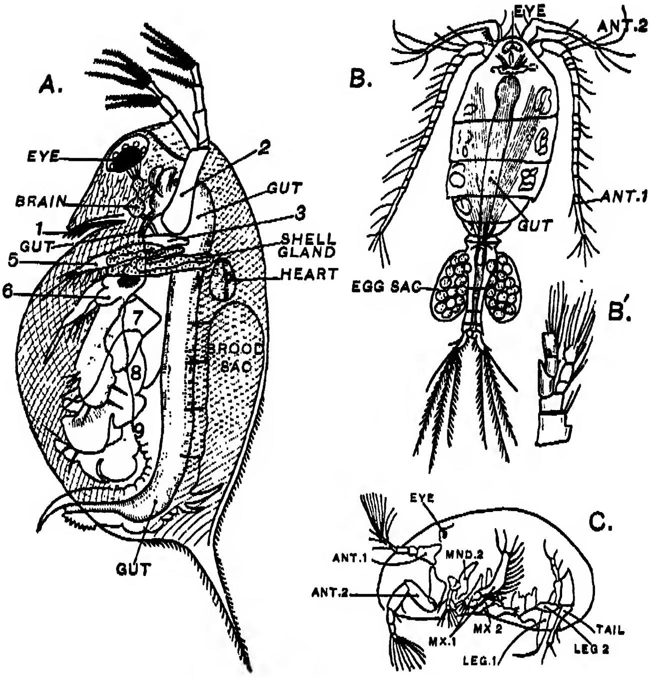


Fig. 596.—Lower Crustaceans (enlarged to various scales)

A, A Water-Flea (*Daphnia*); 1–9, appendages (2 is one of the large rowing feelers). B, Cyclops; ANT. 1, rowing-feeler; ANT. 2, small second feeler. B', A forked rowing limb of Cyclops. C, A Mussel-Shrimp (*Cypris*); ANT. 1 and ANT. 2, first and second rowing-feelers; MND, MX. 1, and MX. 2, jaws.

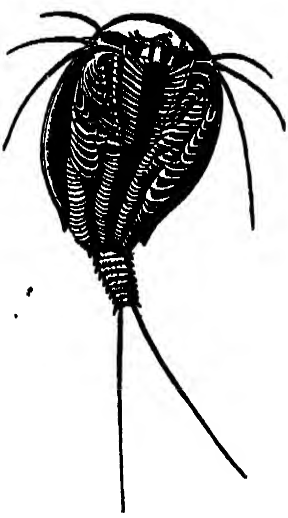


Fig. 597.—Apus, under side, showing numerous overlapping leaf-shaped paddles.

much smaller second feelers perhaps also give some assistance. This is not, however, the only possibility, for the trunk bears four pairs of forked rowing-limbs which are able to swing together in unison, so as to paddle the animal rapidly along.

In WATER-FLEAS (*Cladocera*), such as Daphnia (fig. 596), the first feelers are very small and only useful as sense-organs, but the second pair are of relatively enormous size, and forked at their ends into a pair of branches bearing long feathery bristles. By means of these organs Water-Fleas are able to swim rapidly on their backs in a jerky sort of way. Such larger forms as Apus (fig. 597), with which the Water-Fleas make up the group of LEAF-

FOOTED CRUSTACEANS (*Phyllopods*), also swim on their backs, paddling themselves along by means of the numerous pairs of flattened limbs attached to the trunk.

SWIMMERS AMONG THE HIGHER CRUSTACEA (*MALACOSTRACA*)

The most characteristic swimming organ in all but the Crabs is the long muscular tail, which acts as a fin, the effective stroke being made by a vigorous bending in the downward direction, after which follows a straightening in preparation for the next stroke. In this way a rapid backward movement is brought about, as may be seen in captive specimens of such animals as Prawns, Shrimps, Lobsters, and Cray-Fish. The forked and more or less flattened limbs of this region of the body are known as "swimmerets", and in smaller forms, *e.g.* Prawns and Shrimps, they may be used as paddles for propelling the animal either forwards or backwards, though not so rapidly as in the ordinary backward swimming. It is particularly interesting to note that the last pair of swimmerets are comparatively large and broad, making up with the last joint of the body a "tail-fin" which plays an important part in tail-swimming. When this region is moved upwards in the straightening which precedes every stroke, the broad last pair of swimmerets is folded up so as to present as small a surface as possible to the water, thus reducing the resistance to the upward movement.

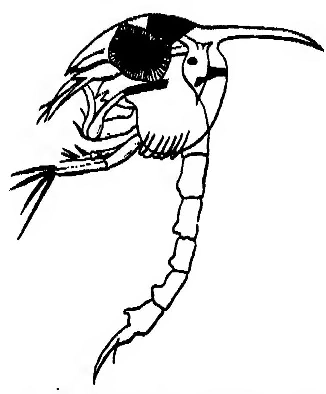


Fig. 598.—A Crab Zoæa (enlarged), showing the well-developed rowing foot-jaws, behind which other limbs are beginning to sprout.

Higher Crustaceans but rarely begin life in the Nauplius form, though they exhibit a great variety of different larval stages, one of these being a Zoæa, characteristically present in the life-history of Crabs (fig. 598). The front part of the body is here covered by a carapace which is often provided with long spines, supposed to balance the body and determine the direction of the swimming movements. The limbs develop from before backwards, none, for example, being at first present

in the tail-region. Swimming is chiefly effected in a way of which no example has so far been given, for the first two pairs of foot-jaws are broad-forked appendages, which do the same work as the feelers of a Nauplius, *i.e.* they are used as oars. Later on, the Crab-zoæa passes into what is termed the Megalopa stage, which possesses a full complement of limbs, swims by its tail, and resembles a minute lobster. The adult Crab in ordinary cases has given up swimming altogether, and its relatively small tail is carried folded up out of harm's way under the front part of the body, which is large and broad.

Fig. 599.—A Swimming or Fiddler Crab (*Thalamita natator*). Note at back the oar-shaped fourth pair of legs.

What are known as Swimming or Fiddler Crabs (fig. 599) have re-acquired the power of swimming possessed by their remote ancestors, which were long-tailed forms, of which the Megalopa stage in the life-history is a reminiscence. They do not, however, swim by means of their tails, as did those ancestors, but have broadened out their last pair of walking-legs into flattened oars.

SWIMMING INSECTS (Insecta)

We have had occasion to note (see vol. i, pp. 354, 357, 376) that although the class of Insects includes for the most part animals eminently adapted to life on land, there are some forms which, either in the adult or larval condition, or in both, live in the water. In such cases characteristic ways of swimming have been developed.

It is but seldom that an aquatic insect swims by means of its wings, but such appears to be the case in a small British species (*Polynema natans*) belonging to the family of membrane-

winged insects (*Hymenoptera*), not distantly related to that which includes the gall-flies. We are reminded here of the Penguins among birds, which employ their wings as fins.

As in the case of the Fiddler Crabs, the chief swimming organs of most aquatic adult insects are the hind-legs, which are well-developed, more or less broadened, and fringed with

Fig. 600.—Freshwater Insects

1, Great Water-Beetle (*Dytiscus marginalis*,; 2, Water Boatman (*Notonecta*); 3, Whirligig Beetle (*Gyrinus*); 4, Pond-Skater (*Gerris*)

bristles (fig. 600). A good instance is afforded by the Great Water-Beetle (*Dytiscus marginalis*) of our ponds, and similar arrangements are found in some of the aquatic bugs, among which the Water-Boatmen (species of *Notonecta* and *Corixa*) swim on their backs (see fig. 600), and when resting keep the oar-like hind-legs stretched out, as is the case under the same circumstances with the sculls of a man using an outrigger boat. The shape of the body facilitates rapid progress.

Some small insects (species of *Scelimena*) belonging to the grasshopper family, and native to India and Ceylon, partly live and feed under water, their swimming-organs being the hind-

legs, upon which are broad outgrowths for giving an increased rowing surface.

The little Whirligig-Beetles (*Gyrinidæ*) (fig. 600), often seen performing complicated curving movements upon the surface of ponds, swim on their backs like water-boatmen, but in this case not only the hind-legs but also the pair in front of them are specialized propulsive organs. Regarding these limbs Sharp (in *The Cambridge Natural History*) remarks:—"Their two hind pairs of legs are beautifully constructed as paddles, expanding mechanically when moved in the backward direction, and collapsing into an extremely small space directly the resistance they meet with is in the other direction".

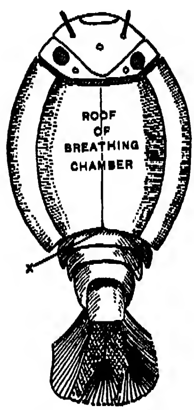


Fig. 601.—Crustacean-like Nymph of a May-Fly (*Prosopistoma*), enlarged. Note the paddling-bristles on the tail.

It is not necessary to say much about the swimming movements of aquatic insect-larvæ. The worm-like young of Gnats and the like simply wriggle through the water. A more specialized method of swimming is exemplified by the early stages of some net-winged insects (*Neuroptera*). This is especially the case with the nymphs of certain May-Flies (such as *Cloëon*), where the three rods which project from the tip of the tail are fringed with especially long bristles, and are supposed to act as paddles. This arrangement is exaggerated in the curious-looking nymph of another kind of May-Fly (*Prosopistoma*) (fig. 601).

SWIMMING MOLLUSCS (Mollusca)

Swimming Molluscs belong to one or other of the three great groups of Cuttle-Fishes, &c. (*Cephalopoda*), Snails and Slugs (*Gastropoda*), and Bivalves (*Lamellibranchia*), especially to the first.

CUTTLE-FISHES, SQUIDS, &c. (Cephalopoda)

The body of a Cuttle-Fish or Squid is symmetrically disposed about a swimming axis, and well adapted by its shape for rapid progression through the water. It is flattened from front to back, the former being kept upwards during the swimming movements, and there is a fin-like expansion round the edge,

where the flat surfaces pass into one another, which appears to be concerned with maintaining the proper balance. The method of propulsion is somewhat remarkable. A large gill-containing cavity is placed on the side of the body which is kept downwards during swimming, and water passes into this by a wide opening at the head-end, making its exit through a muscular tube or funnel. The wall of the gill-cavity is extremely muscular, and by its rhythmic contraction forces water out through the funnel with considerable force, so that the outcoming jet reacts on the surrounding medium and propels the animal backwards with great velocity. Comparison may here be made with a certain kind of toy steam-boat, provided with a small boiler, from which a tube passes out through the stern, conducting steam, that reacts against the water so as to propel the boat with considerable speed. If the tube opened at the bows the miniature craft would move stern first, and the resemblance to a Cuttle-Fish would be still greater. It further remains to be mentioned that a Cuttle-Fish possesses a kind of internal plate-like shell (and a Squid a horn-like "pen") lying close to the surface directed upwards during swimming, and this stiffens the body so as to prevent "wobbling", which would reduce the rapidity of movement. And were there nothing to obviate it, the water would be forced out of the gill-cavity through the wide slit by which it enters; but this is prevented by the existence of two knobs on the wall of the cavity, which, by fitting into corresponding pits, may almost be said to button up this aperture, so that the expelled water is bound to pass through the funnel. The most interesting feature of the Cuttle-Fish's mode of swimming consists in the fact that it is an adaptation of an arrangement of which the primary use is to renew the water in the gill-cavity, as an accessory to breathing.

What has so far been said about the Cephalopods refers more especially to the ten-armed forms (*Decapoda*), which possess eight relatively short sucker-studded "arms" and a pair of longer "tentacles", each of which is broadened out at its end into a sort of sucker-bearing pad. Another group is constituted by eight-armed forms (*Octopoda*), in which there are no long tentacles, but simply the eight short arms. In such a type as Octopus the body is plump and rounded, and not so well adapted for swimming as in an ordinary Cuttle-Fish, while the internal shell

is absent. Although the animal is able to swim like a Cuttle-Fish, but not so perfectly, it has taken to a creeping mode of life, which has led to a corresponding change in shape and general proportions. A long flattened body would obviously be inconvenient under such conditions, for which a short rounded shape is much more suitable.

There are, however, certain eight-armed species which have, so to speak, taken once more to swimming (compare p. 28), and are possessed of new arrangements related to that kind of locomotion. One of the most interesting of these is the Argonaut, or Paper Nautilus (*Argonauta argo*), in which the female is remarkable as being the owner of a thin external shell, into which the greater part of the body can be withdrawn (fig. 602). This elegant structure is beautifully ribbed, and provided with a sharp keel. It has been formed or secreted by the first pair of arms, which are large, backwardly directed, and broadened out at their ends into broad lappets. During life these expansions clasp the shell firmly on the outside. It was formerly thought that they could be raised above the water and used as sails, but this would appear to be pure imagination, though the animal has often been figured in accordance with this erroneous idea. Regarding this interesting creature Rymer Jones (in *The Animal Creation*) makes the following comment:—"It was, indeed, to this Cephalopod that the ancients assigned the honour of having first suggested to mankind the possibility of traversing the sea in ships; and nothing could be more elegant than the frail bark in which the Argonaut was supposed to skim over the waves, hoisting sails to the breeze, and steering its course by the assistance of oars provided for the purpose. It is almost a thankless office to dispel so pretty a fiction: modern researches, however, serve to show that its sailing capabilities have been much exaggerated." In fact, a Paper Nautilus swims precisely like a Cuttle-Fish, by the ejection of water through the funnel,

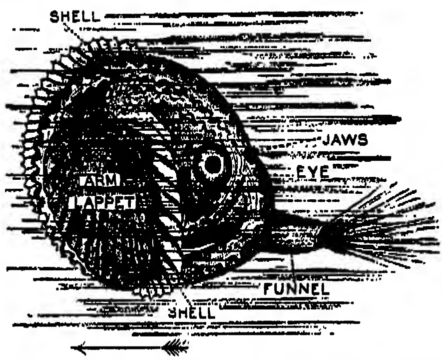
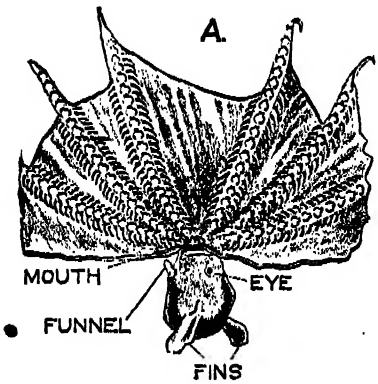


Fig. 602.—Female Argonaut (*Argonauta argo*), reduced, swimming backwards by ejection of water through the funnel. The arrow indicates direction of movement.

having previously drawn back into her shell and snugly coiled up the slender arms. Swift backward movement is facilitated by the sharp keel on the shell, which acts as a cut-water. Although better adapted for swimming than the Octopus, this creature spends much of its time in crawling upon the sea-floor.



In other animals related to the Octopus we find that the eight arms which are arranged in a circle round the mouth are more or less connected by a web-like membrane, and thus collectively form a muscular hollow expansion, which by alternate contraction and relaxation acts very much like the umbrella of a medusa (see p. 18), and forms an auxiliary, or in extreme cases the

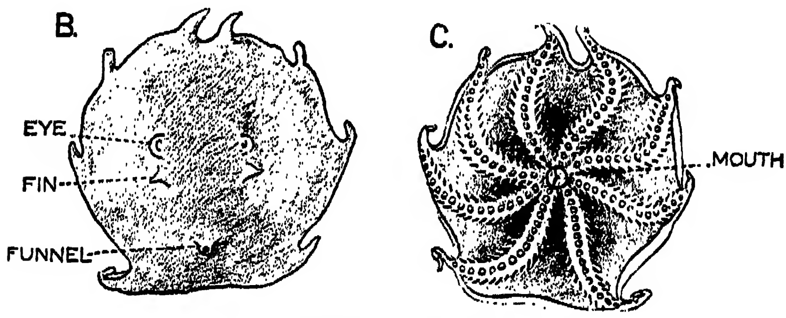


Fig. 603.—Specialized Swimming Octopods (reduced)

A, Cirroteuthis; the swimming-bell has been partly cut away. B and C, Upper and under sides of Opisthoteuthis. In both cases each of the eight arms bears a central row of suckers, flanked by hooks on either side.

chief, swimming organ (fig. 603). There is one family (*Cirroteuthidæ*) where this line of evolution has greatly modified the proportions of the body. In one such form (*Cirroteuthis*) the swimming umbrella is of relatively enormous size, and the small body is provided with a well-marked pair of fins. Modification is carried still further in a related deep-sea form (*Opisthoteuthis*), where the animal is entirely converted into a flattish swimming-disc.

SWIMMING SNAILS AND SLUGS (GASTROPODA)

The most typical members of this group creep upon the broad muscular expansion of the under side of the body to which the

name *foot* is applied, and this method of progression is familiarly illustrated by ordinary land snails and slugs. None of the members of the order (*Pulmonata*) to which these belong are able to swim, though some of the freshwater forms, such as the Pond Snail (*Lymnæus*), are often met with floating at the surface

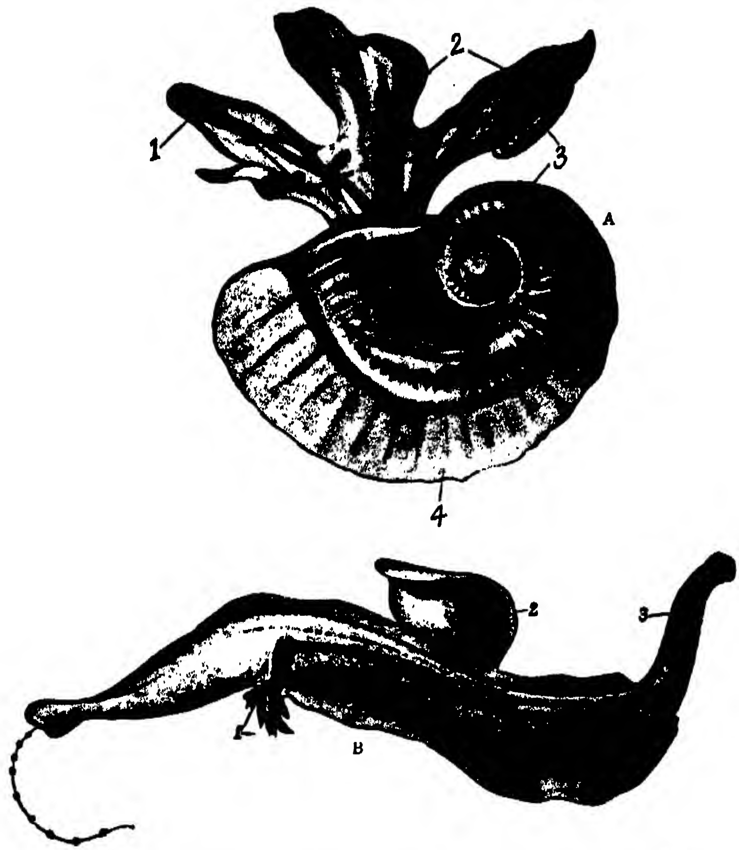


Fig. 604.—Heteropods (drawn in the swimming position, with under surface directed upwards)
A, Atlanta; 1, snout; 2, swimming foot; 3, operculum. B, Pterotrachea; 1, gills; 2, swimming foot; 3, snout.

of the water, foot upwards, and holding on to the surface film. But both in the order of Fore-gilled Snails (*Prosobranchia*) and that of Hind-gilled Snails (*Opisthobranchia*) species are included in which the foot, or part of it, is more or less completely converted into one or more fins, which are sometimes very perfectly adapted for swimming.

Fore-gilled Swimmers (*Prosobranchia*).—These include a remarkable group (*Heteropods*), which lead a pelagic existence,

i.e. live in the open sea, having entirely abandoned the creeping habit for a free-swimming mode of life. Their bodies are translucent, and present a great variety in shape, according to the species (fig. 604). Those which are least modified are provided with a spiral shell: in a further stage of specialization the shell has been reduced to a small cap-shaped structure, and in the most modified forms the shell has disappeared altogether, and the animal is much elongated. But in all these cases the foot is more or less converted into a flattened fin, the owner of which swims with its upper surface directed downwards.

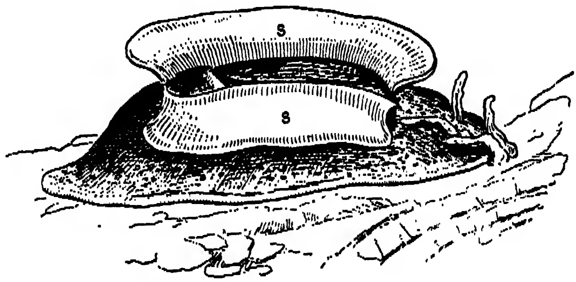


Fig. 605.—Sea-Hare (*Aplysia*), creeping. s s, Swimming flaps (parapods) turned back

HIND-GILLED SWIMMERS (*Opisthobranchia*).—The hind-gilled Gastropods are divided into those which typically possess a shell (*Tectibranchs*), and the shell-less animals known as Sea-Slugs (*Nudibranchs*). It is among the former that most of the swimming forms are found. In some of them creeping is the chief means of progression, but each side of the foot is provided with a muscular flap (*parapod*), and these two expansions can be moved up and down so as to produce swimming movements. A common example of this sort of arrangement is found in the Sea-Hare (*Aplysia*) (fig. 605).

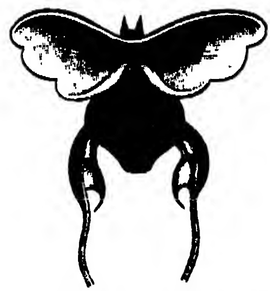


Fig. 606.—A Wing-footed Snail (*Hyalea*) or Sea-Butterfly (somewhat enlarged), showing swimming lobes.

Specialization for swimming is carried very much further in the *Wing-footed Snails* (Pteropods), formerly believed to constitute a distinct order of Molluscs (fig. 606). These little translucent creatures are of thoroughly pelagic habit, living in vast shoals at the surface of the ocean, and forming an important part of the food of whales and other animals. Some of them possess a glassy shell of various shape, while others again are quite shell-less. In either case the main part of the foot has been

reduced to very small dimensions, while a pair of muscular flaps, growing out from its sides, look almost like wings, and serve as efficient fins. By means of these organs Pteropods may almost be said to flit through the water, and are sometimes metaphorically called "sea-butterflies".

The shell-less SEA-SLUGS (*Nudibranchia*) are even more characteristically creeping forms than their shell-bearing hind-

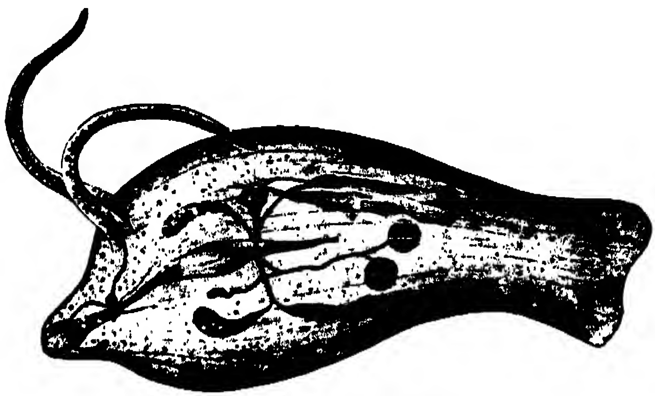


Fig. 607.—A Swimming Sea-Slug (Phyllirhoë) × 4

gilled relatives, but some of them are able to swim. The most remarkable instance of this is presented by a small pelagic creature, *Phyllirhoë*, in which the body is strongly compressed from side to side, while the foot is altogether absent, a very unusual character among molluscs. Swimming is effected by undulating movements of the body, the hinder end of which is rounded into a sort of tail-fin (fig. 607).

SWIMMING BIVALVE MOLLUSCS (LAMELLIBRANCHIA)

Bivalve Molluscs are mostly adapted to a burrowing life, while some of them, such as Oysters, are fixed when adult. The shell is primarily a protective organ, but in a few cases it has acquired a new use, having become a means of swimming. This is the case, for instance, in many of the Scallops (*Pecten*) and File-Shells (*Lima*). It has been explained elsewhere (vol. i, p. 330) that the two pieces or valves of the shell are movably united together by a sort of hinge. One or two strong bands of muscle (adductor muscles) run across from one valve to the other, and it is obvious that when these contract the shell is closed. When

they relax the shell opens or "gapes" as a result of the elasticity of a fibrous band (ligament), or it may be a compressible pad (cartilage), placed in the region of the hinge. File-Shells may often be observed lying on the sea-floor in shallow water, with the shell widely gaping, and as the edge of the mantle, a fold of the body-wall which lines the valves, is brightly coloured and bears a fringe of sensitive tentacles, the appearance of the animal is both striking and beautiful. When disturbed these molluscs swim in a jerky way by means of the shell, which is alternately opened and closed with considerable rapidity (fig. 608). Closure is effected by the powerful adductor muscle (for only one is present here), and opening by elasticity. Scallops are closely related and swim in the same manner, but their hues are even brighter, for the mantle edge not only bears a fringe of tentacles, but possesses numerous small red eyes.

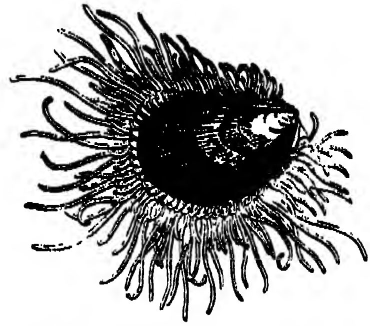


Fig. 608.—A File-Shell (*Lima*) with fringed mantle fully expanded (reduced).

A bivalve which when adult burrows in mud may swim in the manner just described during an early period of its existence. This is the case in the Freshwater Mussels (*Unio* and *Anodon*), which begin their independent existence as free-swimming larvæ (*glochidia*), propelled through the water by the agency of their triangular shells, which are quite unlike the shells of the adult (fig. 609).

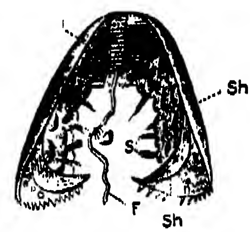


Fig. 609.—Larva (*Glochid*...), of Freshwater Mussel (much enlarged). F, Sticky thread (byssus) cut short; M, adductor muscle for closing shell Sh; S, sense organs.

CHAPTER XLIII

MUSCULAR LOCOMOTION—PRIMITIVE VERTEBRATES AND FISHES AS SWIMMERS

Some of the Primitive Vertebrates (*Protochordates*) swim when adult, or during the early part of their lives, and Fishes are for the most part eminently adapted for this kind of locomotion. They are best considered under separate headings.

PRIMITIVE VERTEBRATES (PROTOCHORDATA) AS SWIMMERS

SEA-SQUIRTS, TUNICATES, or ASCIDIANS (*Urochorda*).—It is scarcely possible to imagine a creature more completely adapted to a fixed mode of life than an ordinary Sea-Squirt, such as Ascidia (fig. 610), which, as to its shape, resembles nothing so much as one of the skin bottles used in the East. One end is attached, and at the other are two apertures, into one of which, the mouth, currents of sea-water constantly stream as the result of ciliary action, making their exit through the [illegible] which is somewhat on one side. There is no trace of that characteristic vertebrate structure, the notochord, which has been aptly called "the forerunner of a backbone". But if we follow the life-history of this animal we shall find that it hatches from the egg as a free-swimming larva, not unlike a tadpole in appearance. This propels itself by means of a muscular tail, that is stiffened

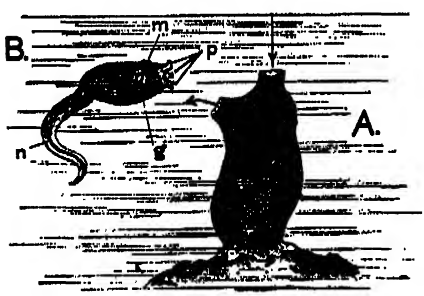


Fig. 610.—A Sea-Squirt (*Ascidia*)

A, Adult (reduced) attached to rock; arrows show course of food-supplying and waste-removing currents. B, Free-swimming tadpole larva (enlarged); g, gill-slit; m, mouth; n, notochord in tail; p, sticky knobs by which the larva later on fixes itself.

by a gelatinous notochord, to which the muscles are attached, these constituting a flattened mass on each side, by the agency of which the tail is drawn alternately to right and left. Later on, the larva fixes itself by the head-end, and its tail gradually diminishes and ultimately disappears entirely. This is a good instance of economy, for to keep the tail would be to maintain an organ no longer serving any useful purpose.

In one small group of pelagic Ascidians (*Appendicularia*, &c.) the tail is retained throughout life as the means of locomotion, and probably these forms resemble in many respects the ancestors from which the ordinary fixed Sea-Squirts have taken origin.

We have not yet exhausted the possibilities of locomotion among the Tunicates, for many of them, besides the members of the small group just mentioned, are free-swimming, translucent pelagic forms, some of which are colonial. These propel themselves by ejection of a stream of water, somewhat after the cuttle-fish manner. We may take as a type the Barrel Ascidian (*Doliolum*), in which the mouth and atrial aperture, instead of being close together, are wide openings at opposite ends of the body (fig. 611). Partly by means of ciliary action currents of water flow into the mouth and out at the atrial aperture. These are related not only to breathing (as in Cuttle-Fishes), but also carry into the body the small organisms and organic particles which constitute the food. So far as respiration and feeding are concerned, ciliary action would suffice, as it does in the fixed forms, but it is not vigorous enough for swimming purposes. To effect this kind of movement by reaction against the water of the outwardly-flowing current, the body of the animal is encircled by a number of muscle-bands, comparable to the hoops of a barrel. These contract and relax, causing water to alternately enter and leave the body, the outward flow taking place with sufficient force to propel the animal in a forward direction.

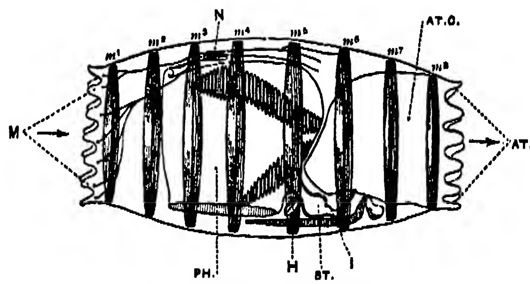


Fig. 611.—Barrel Ascidian (*Doliolum*)

M, Mouth; PH., pharynx, showing two rows of gill-slits of one side. ST., stomach; I, intestine; AT.C., atrial cavity; AT., atrial aperture; H, heart; m^1–m^8, muscle-bands; N, central nervous system, from which nerves are seen running off. Course of water currents indicated by arrows.

THE LANCELET (*Amphioxus*).—The chief features of the anatomy of this small, somewhat fish-like creature have elsewhere been given (see vol. i, p. 293). It may be repeated here that the body is greatly flattened from side to side, and stiffened by a gelatinous notochord which runs from one end of the animal to the other underneath the nerve-cord. This supporting rod is covered by a firm fibrous sheath, continuous with partitions of a similar nature which run between the angular segments into which the muscles of each side are divided. The muscle-fibres are disposed longitudinally, and by their alternate contraction on the two sides of the body are able to bring about undulating swimming movements. The notochord is elastic, and straightens the body after it has been bent on one side by muscular action.

FISHES (PISCES) AS SWIMMERS

The fishes which are least specialized for swimming, such as Lampreys and Eels, may be said to "wriggle" through the water by undulating the body from side to side. In such instances the firm axis of the body, though presenting a great advance in complexity upon the simple notochord of the Lancelet, is still very flexible and elastic, lending itself readily to the sinuous swimming movements. As in all fishes, the smooth and slimy skin presents but little resistance to passage through the water.

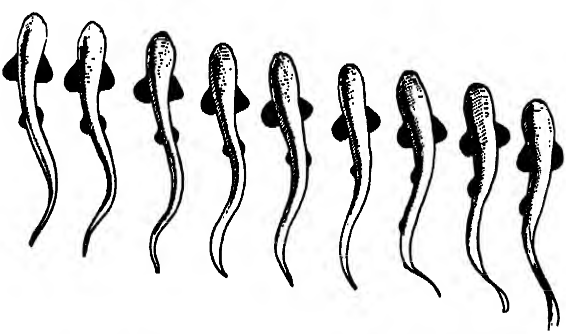


Fig. 612.—Phases of Movement in a Swimming Shark, seen from above (diagrammatic)

Advancing upwards in the scale we find that the fins, especially the tail-fin, are largely concerned with locomotion. In SHARKS and DOG-FISHES (*Elasmobranchii*), for instance, although the body still describes undulating movements from side to side (fig. 612), the chief agent of propulsion is the powerful tail-fin, which in this case is markedly unsymmetrical (heterocercal), there being a large upper lobe, into which the spine is continued,

and a small under lobe (fig. 613). Although these forms can swim at all levels, they are in the main "ground-fishes", and, being heavier than water, naturally sink to the bottom unless this is obviated by active contractions of the muscles. Indeed, the working of this sort of tail-fin, if left to itself, brings about a downward movement, for it causes the hinder region of the body to rise up and the head to be correspondingly depressed, so that the animal is enabled to propel itself with great rapidity to its favourite haunts far below the surface. If, however, the fish

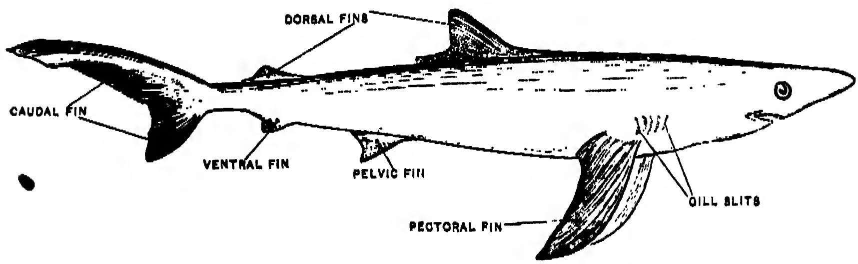


Fig. 613.—Blue Shark (*Carcharias glaucus*)

wishes to move horizontally or upwards, it is enabled to do so by adjusting the broad pectoral fin so as to steer the animal in the required direction. The higher the front edges of these fins as compared to their back edges, so much the more is a tendency to an upward path developed, and the downward bias resulting from the peculiar shape of the tail-fin is either just counterbalanced, when horizontal movement is the net result, or more than compensated, when an oblique upward movement is brought about.

The dominance of Ordinary Bony Fishes (*Teleostei*) at the present time is largely due to the fact that in average cases they have become adapted to rapid swimming as regards both shape and structure. The most notable character is the possession of an outwardly symmetrical (homocercal) tail-fin, which propels the fish straight forwards, while the presence of a swim-bladder has reduced the specific gravity. Dean (in *Fishes, Living and Fossil*) thus describes a case where the adaptations to rapid progression have reached their maximum:—"In an example of a swift-swimming fish some of the most striking peculiarities of the aquatic form may be seen. The Spanish Mackerel [*Scomber colias*] shows admirably a stout, spindle-like outline; its entire surface is

accurately rounded, and there appear no irregular points which could retard the forward motion of the fish. Even in the wedge-shaped head the conical surface has been made more perfect by the tightly-fitting rims of the jaws, by the smoothly-closed gill-shields, and by the eyes' accurate adjustment to the head's curvature. Viewed from in front, the fish's outline appears as a perfect ellipse, and seems surprisingly small in size: the fins, which appear so prominent a feature in profile, can now be hardly distinguished; above and below they form keels, sharp and thin. In side view the vertical or unpaired fins are seen surrounding the hinder region of the body: they resolve themselves into *dorsal*, *anal*, and *caudal* elements; the former are low and stout, elastic in their

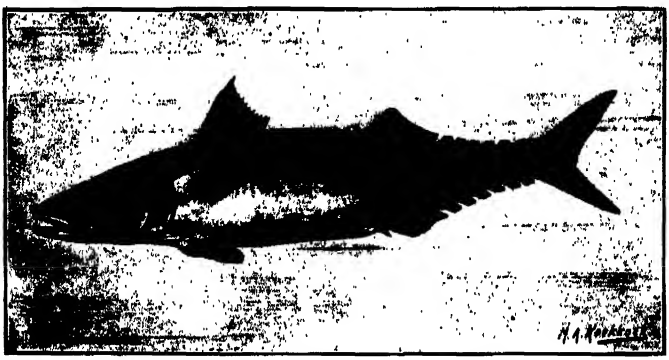


Fig. 614.—Common Mackerel (*Scomber vernalis*)

firm cut-water margin, deeply notched and interrupted posteriorly, where useless elements have been discarded; the caudal is broadly forked, stout in its supporting rays, strong in power of propulsion. At its sides a remarkable ridge has been developed, functioning as a horizontal keel, and preventing the stroke of the caudal from varying from the vertical plane. The lateral or paired fins, *pectoral* and [*pelvic*], may rotate outward and arrange themselves in the line of the fish's motion, so that in a somewhat horizontal plane they may, like the unpaired fins, function as keels. When thus erected, the paired fins present a firm anterior margin, which serves as a cut-water. While thus somewhat similar in function to the vertical fins, the [pelvics], and especially the pectorals, may acquire additional uses: they may serve as delicate balancers, or may aid in guiding or arresting the fish's motions. In further conformity to aquatic needs, the entire surface of the

fish is notably slime-covered, and although perfectly armoured by plates and scales, yet presents no point of resistance to forward motion." These remarks are equally applicable to the Common Mackerel (*Scomber vernalis*, fig. 614). It has been shown by mathematical calculation that the shapes of fishes such as the one just described are of the kind best suited to rapid movement in water.

Some bony fishes have evolved on different lines from those indicated above, in accordance with special modes of life. Many ground-fishes, for instance, are creatures of comparatively sluggish habits, and naturally differ in many respects from their swift-swimming cousins. An extreme case is that of Flat-Fishes, which are greatly flattened from side to side, and are incapable of swimming in the vertical position. During the whole adult life they both rest and move with one side of the body downwards, and when they swim, do so with an undulating movement of the body. Yet for some time after hatching, these fishes are of normal appearance and swim in the usual way, a fact which helps to prove that these highly-specialized forms have descended from ancestors of more average attributes. It is not surprising to find that Flat-Fishes never possess a swim-bladder.

Eels, again, though they have been mentioned in illustration of a simple mode of swimming (see p. 40), are not primitive forms, but have been evolved from fishes endowed with greater powers of swimming, and their peculiar characters are adaptations to life in the mud of ponds and streams.


Fig. 615.—Sea-Horse (*Hippocampus*)

An unique method of swimming is practised by the little Sea Horse (*Hippocampus*), which spends most of its time attached by its curly tail to sea-weed. Here all the fins have been suppressed except the pectorals and a well-marked dorsal (fig. 615). By means of the rapid movement of the latter from side to side the fish is able to swim with the long axis of its body in a vertical position, *i.e.* at right angles to its direction in an ordinary fish during progression. The contrast is as great as that between a dog and a human being when walking or running, the long axis of the body in these cases being respectively horizontal and vertical.

The remarkable peculiarities of the Sea-Horse are simply adaptations to an unusual mode of life. Its remote ancestors probably resembled sticklebacks in appearance.

The last fishes to be mentioned in this connection are the remarkable *Skates* and *Rays*, which belong to the same order as

Fig. 616.—Eagle-Rays (*Myliobatis aquila*) swimming (much reduced)

Sharks and Dog-Fishes (*Elasmobranchii*). The body is in this case flattened from above downwards (at right angles to the direction of compression in flat-fishes), and is of quadrangular form, the sides being constituted by the enormous pectoral fins. It is these fins which, by their upward and downward movement, enable the fish to flap its way through the water (fig. 616).

CHAPTER XLIV

MUSCULAR LOCOMOTION. AMPHIBIANS, REPTILES BIRDS, AND MAMMALS AS SWIMMERS

AMPHIBIANS (Amphibia) AS SWIMMERS

Although recent Amphibians are clearly marked off from recent Fishes, they are undoubtedly descended from fish-like ancestors, and both in structure and habits constitute a sort of half-way house between completely aquatic and thorough-going terrestrial Vertebrates. In almost all cases an Amphibian begins life as an aquatic tadpole larva (fig. 617), which is to all intents and purposes a fish, and swims by means of a long muscular tail, flattened from side to side and bordered by a membranous fin, which, however, is not supported by hard fin-rays, as is the case in a fish.

Fig. 617.—Tadpoles and young Frogs

There are three groups of Amphibia represented among living animals, *i.e.* Tailed Amphibians (*Urodela*), Tailless Amphibians (*Anura*), and Limbless Amphibians

TAILED AMPHIBIANS (*Urodela*).—The Newts and Salamanders which constitute this group are for the most part of thorough aquatic habit, and even those of them which are most adapted to a terrestrial life are found in damp places, and have by no means lost the power of progression in water. Average cases are presented by the Newts or Efts, of which three species are native to Britain, *i.e.* the Great Crested Newt (*Molge cristatus*), the Common Newt (*M. vulgaris*), and the Palmated Newt (*M. palmatus*). These animals and their immediate allies are terrestrial except during the egg-laying season, at which time they take to the water. The chief swimming organ is the strong flattened tail, which is moved from side to side like that of a tadpole. Its efficiency is increased by the presence of a membranous fin, and it is remarkable that this becomes larger when its owner temporarily abandons the land for the water. At the same time the males develop a crest along the upper side of the body, and this may also assist in swimming. It is particularly large in the Great Crested Newt, and its edge is saw-like (fig. 618). The limbs, no doubt, assist in swimming, and in the male of the Palmated Newt the hind-feet become webbed at the time when the crest is developed. Some species of Newt, however, have been seen swimming rapidly by undulating the body and tail in an eel-like manner, the limbs being at the same time folded back against the body. From this it would appear to follow that in such animals the limbs are at most of secondary importance in progression through the water.

The well-known Spotted Salamander (*Salamandra maculosa*) of Europe, Africa, and South-western Asia, though belonging to the same family as our native Newts (*Salamandridæ*), contrasts markedly with them as regards its habits. Though dependent on moisture for its well-being, it only enters the water voluntarily during the egg-laying season, and even then only immerses the hinder part of its body. Gadow (in *The Cambridge Natural*

History), after describing the difficulty of finding this animal in dry weather, even in places most affected by it, says:—"The same place after a thunder-storm will be literally swarming with sleek, lively salamanders in search of earthworms and all kinds of insects, especially at dusk or during the night. They disappear in the autumn, in October, to hibernate in the ground, out of the reach of frost, and they reappear again in April. Later on they

Fig. 618.—Great Crested Newt (*Molge cristatus*) above, and Spotted Salamander (*Salamandra maculosa*) below

congregate at little springs, always at running water, to reach which they have often to make long migrations. This is the only time when these thoroughly terrestrial creatures approach water, in which they easily get drowned." It would appear, however, that if thrown into water the Spotted Salamander is able to swim vigorously by powerful side-strokes of its strong flattened tail, though this is not so well suited for the purpose as that of a Newt (see fig. 618).

While the tailed Amphibians, so far mentioned, are either, like Newts, semi-terrestrial when adult, or, like the Spotted Salamander, entirely terrestrial, the remaining members of the group live mostly or entirely in the water during the whole of

their lives. This is the case, for instance, with the Fish-Salamanders (*Amphiumidæ*), which include the Giant Salamander (*Megalobatrachus maximus*) of China and Japan, and the Mississippi Salamander or Hell-bender (*Cryptobranchus lateralis*). Both of these are tail-swimmers. Another interesting North American species of the same family, the Three-toed Salamander (*Amphiuma means*), has specialized along much the same lines as eels among bony fishes (see p. 43), and swims by undulations

Fig. 619.—Mud-Eel (*Siren lacertina*), reduced

of its elongated body. The limbs are much reduced in size, and are provided with only two or three digits.

The same kind of modification is carried even farther in the best-known member of another family (*Proteidæ*), *i.e.* the Olm (*Proteus anguineus*). This creature, which is blind and of white or pinkish colour, is a native of South-west Austria, where it lives in underground streams. The small fore- and hind-limbs are respectively provided with three and two digits (see vol. i, p. 249).

The most specialized family of tailed Amphibians, however, is that of the Siren Salamanders (*Sirenidæ*), including two species from the south-east of the United States. In both of these the

hind-limbs have entirely disappeared, and the fore-limbs are folded back against the body during swimming. The more familiar of the two species (fig. 619) is locally known as the Mud-Eel (*Siren lacertina*), and possesses four digits to the fore-limb, while there are only three digits in the other species (*Pseudobranchus striatus*), which is native to Georgia.

TAILLESS AMPHIBIANS (*Anura*).—This subdivision of the Amphibia includes all the forms familiarly known as Frogs and

Fig. 620.—Surinam Water-Toad (*Pipa Americana*) swimming (reduced)

Toads, among which is exemplified an even greater variety of habit than is displayed by the tailed Amphibians. Many species are thoroughly aquatic, others are terrestrial, and some of the latter live in trees. In most cases these creatures seek the water during the egg-laying season, and many of them are expert swimmers. The organs of propulsion are the relatively long and powerful hind-limbs, the efficiency of which is often increased by the presence of well-developed webs between the toes.

Examination of a Frog in the act of swimming shows that the legs are simultaneously pushed back and widely separated from one another, being then drawn up again and at the same time brought together, so as to react upon the wedge-shaped mass of

water between them. Meanwhile the arms are folded upon the breast. As far as this leg-action is concerned, a comparison may be made with a man swimming by means of his legs only. But the broad, flat, webbed feet of the Frog confer a great additional advantage, and render the comparison an imperfect one.

Among entirely aquatic species may be mentioned some of the Tongueless Toads (*Aglossa*), of which two notable examples are the African Clawed Toad (*Xenopus lævis*) and the Surinam Water-Toad (*Pipa Americana*), native to Guiana and some other parts of South America. In both these forms the feet are broad paddles of relatively large size (fig. 620).

Other thoroughly aquatic species are the "Water Frogs", of which the Bull-Frog (*Rana Catesbiana*) of North America, and the Edible Frog (*R. esculenta*), the kind eaten on the Continent, may be taken as typical examples. Although both the Common or Grass Frog (*R. temporaria*) and the Toad (*Bufo vulgaris*) are of terrestrial habit, they are both good swimmers, and are found in ponds, &c., during the egg-laying season.

REPTILES (REPTILIA) AS SWIMMERS

Swimmers are represented in all the five orders of living Reptiles, *i.e.* Crocodiles and Alligators (*Crocodilia*), Lizards (*Lacertilia*), Snakes (*Ophidia*), Turtles and Tortoises (*Chelonia*), and Tuataras (*Rhynchocephala*).

CROCODILES AND ALLIGATORS (*Crocodilia*).—The members of this order are eminently aquatic, and possess a powerful swimming tail, flattened from side to side, and provided with a saw-edged crest on its upper surface. There is a good deal of variation in the structure of the fore- and hind-feet. The former may be partly webbed, and the latter are always more or less so. Taking the Nile Crocodile (*Crocodilus Niloticus*) as a type (fig. 621), we find that the fore-feet are webbed at the base, while a well-developed membrane connects together the outer toes of each hind-foot. The spindle-shaped body may be regarded as an adaptation to rapid locomotion through the water, which is chiefly effected by powerful side-strokes of the tail. The fore-limbs do not appear to be of much use in this respect, for they are laid back against the body, much as is the case in a Frog during swimming. The hind-limbs, on the other hand,

THE WATER-MONITOR (*Varanus salvator*)

This Lizard, which may be as much as 6 or 7 feet in length, ranges from India to Australia, and is a representative of a widely distributed family (*Varanidæ*), the members of which exhibit a number of structural adaptations to different modes of life. In this case the most noticeable feature is the long powerful swimming-tail, which is rendered more efficient by being greatly flattened from side to side, much as in a Crocodile.

The Water-Monitor is particularly fond of birds' eggs, which it eats in a rather curious manner. Seizing one of these in its jaws, it raises its head, breaks the shell, and swallows the contents. The empty shell is then ejected.

THE WATER-MONITOR (VARANUS SALVATOR)

are used as subsidiary propulsive organs, and there is a cut-water edge on the outer side of each which easily cleaves the water when the legs are drawn forward in preparation for their backward stroke. It may also be noted that the smooth surface of the horny plates which cover the body reduces friction with the surrounding water. The curious adaptations which the breathing organs exhibit in adaptation to the mode of life have been noticed elsewhere (vol. ii, p. 424).

LIZARDS (*Lacertilia*).—The members of this very large group exhibit a series of adaptations to almost every sort of condition,

Fig. 621.—Nile Crocodiles (*Crocodilus Niloticus*, swimming

and some of those which spend more or less of their time in the water are expert swimmers.

The Sea Lizard (*Amblyrhynchus cristatus*) of the Galapagos Islands is remarkable on account of its marine habits (see vol. ii, p. 192). The body and tail are flattened from side to side, especially the latter, and, as might be anticipated, the animal is a tail-swimmer (fig. 622). The large Lizards known as Monitors (*Varanus*), which range from Africa through South Asia to Australia, mostly live near water and swim with more or less facility, the swimming organ being the tail. It is very interesting to notice that this organ is flattened to a varying extent in the

different species, the aquatic habit and power of swimming being most marked in cases where the flattening is greatest. A typical instance of considerable adaptation in this direction is afforded by the Water Monitor (*Varanus Salvator*), a species which ranges from India to North Australia, and concerning which Annandale says:—" *Varanus Salvator* is common in Lower Siam, where it is equally at home on land, in water, and among the branches of trees. . . . When in the water the lizard swims

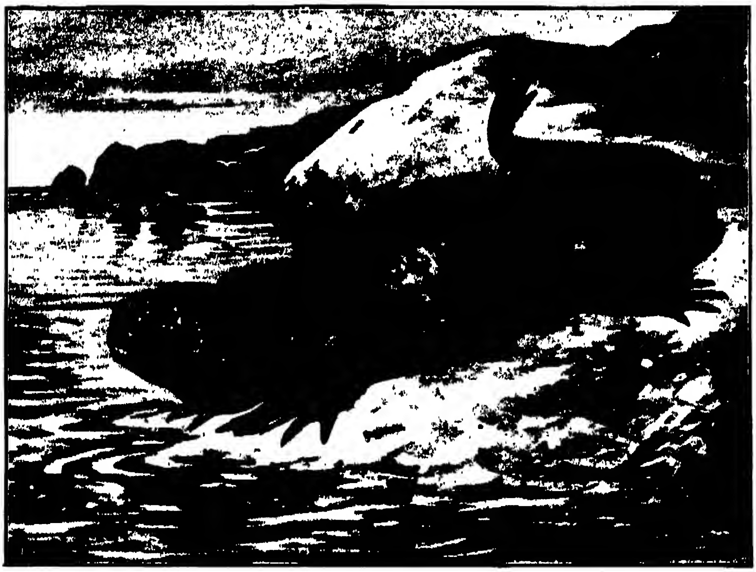


Fig. 622.—Galapagos Sea-Lizard (*Amblyrhynchus cristatus*), reduced

beneath the surface, the legs being closely applied to the sides, and the tail functioning both as oar and rudder."

The large American Lizards known as Iguanas, which belong to the same family (*Iguanidæ*) as the Sea Lizard, possess a long powerful tail, which is strongly flattened from side to side, and by means of which they swim in much the same way as the Water Monitor. The Common Iguana (*Iguana tuberculata*) of tropical America and the West Indies lives for the most part on trees close to the water, into which it dives when alarmed. The Ring-tailed Iguana (*Cyclura carinata*) of the West Indies is also a good swimmer (see fig. 433, vol. ii, p. 193). Quite a different method of progression through the water is exemplified by the American Basilisk (*Basilicus Americanus*), which is another

member of the Iguana family. The habits of these creatures are described by Gadow (in *The Cambridge Natural History*) as follows:—"These creatures are very common amidst the luxuriant vegetation on the banks of the rivers of the Tierra Caliente of Mexico and in Guatemala. They lie upon the branches of trees, preferring those which overhang the water, into which they plunge at the slightest alarm. The high crests, being restricted to the male sex, are not essential to their swimming; they propel themselves by rapid strokes of the fore-limbs, letting the long rudder-like tail drag behind."

The numerous Lizards which constitute the family *Agamidæ* play the same part in the Old World that Iguanas and their allies do in the New. They range from Australia through South Asia and the African continent, and include some few forms which are tail-swimmers. The Water-'guana of Queensland (*Physignathus Lesueuri*) will serve as an example. It is about 18 inches long, with laterally-flattened body and tail, which are provided with a narrow saw-edged crest on the upper side. Semon (in *The Australian Bush*) states that these creatures "are expert swimmers, and like to perch in the branches of the tea-trees, and on the tree-stumps of the river-side, whence they let themselves drop into the water with a big splash if anyone is approaching . . ."

SNAKES (*Ophidia*).—Some few Snakes are semi-aquatic in habit, and progress in the water by undulating movements, commonly keeping the head raised more or less above the surface. Examples are found in the gigantic Anaconda (*Euneces murinus*) of tropical South America, the common Grass Snake (*Tropidonotus natrix*) of Britain, the Wart-Snake (*Acrochordus Javanicus*) of the Malay Peninsula, Java, and New Guinea, and the Water Viper (*Ancistrodon piscivorus*) of the United States.

Marine Snakes.—A number of Snakes, belonging to several different families, inhabit the sea, and it may be the adjacent estuaries. The large majority of these are included in a special family (*Hydrophinæ*), of which all the members are extremely poisonous, and have their head-quarters in the Indian Ocean and the western part of the South Pacific, though some of them range as far as the west coast of Mexico and Central America. The most interesting feature about these Reptiles is the way in which they are adapted to their mode of life, for the tail is

laterally flattened and serves as a propeller, while in some cases the trunk is also specialized in the same way. The former character is well seen in the species figured (*Hydrus bicolor*, fig. 623), which is one of those most widely distributed, as it ranges from the Cape of Good Hope to the west coast of America. Sea-Snakes are social in habit, and usually swim with

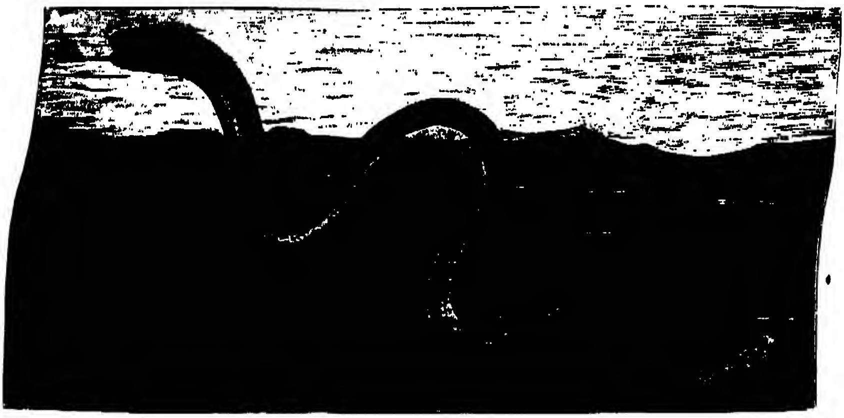


Fig 623.—A Sea-Snake (*Hydrus bicolor*) swimming (reduced)

the head projecting above the surface. They dive when disturbed, and while under water their valvular nostrils are closed.

TURTLES AND TORTOISES (*Chelonia*).—These Reptiles present a very interesting series of gradations between limbs suited for progression on land and those much specialized for swimming purposes. Such a typically terrestrial form, for example, as the Grecian Tortoise (*Testudo Græca*) possesses stumpy legs, of which the short toes are provided with claws, and quite devoid of webs. Its carapace is strongly arched. The European Pond-Tortoise (*Emys orbicularis*) is flatter, but has limbs of much the same general character, though the extremities are broadened, and extensive webs spread between the somewhat longer toes.

Much greater specialization is exhibited by the Soft Tortoises (*Trionychoidea*), which live in some of the rivers of Asia, Africa, and North America, ranging also into estuaries and even into the sea, being thus intermediate in habit between purely fresh-water and purely marine forms. The body is here a good deal flattened, while the broadened limbs end in extensively-webbed paddles, of which only the three inner toes bear claws (fig. 624). The limbs are worked horizontally, and under ordinary circum-

stances those on one side alternate with those of the other side. On occasion, however, the two front paddles can be used together, in which case the swimming is more rapid. From this case we pass on to the purely marine Turtles (*Chelonidæ*), in which the limbs are converted into flippers, the fore ones being much larger than the others. The digits are much elongated for the support of these swimming organs, which are used diagonally, each fore-

Fig. 624.—Nilotic Soft Tortoise (*Trionyx triunguis*) swimming (reduced)

flipper moving forwards and backwards at the same time as the hind-flipper of the opposite side. In the Hawkbill Turtle (*Chelone imbricata*) only the two inner digits bear claws, and this is the case with young individuals of the Loggerhead Turtle (*Thalassochelys caretta*), but in the adults of this species there is only one clawed digit, *i.e.* the first or innermost. The same digit is, as a rule, the only claw-bearing one in the Edible Turtle (*Chelone mydas*). The largest and most specialized of recent Chelonians is the Leathery Turtle (*Dermatochelys coriacea*), which is the only living representative of its family (*Sphargidæ*). Its flippers are entirely devoid of claws (fig. 625).

TUATARAS (*Rhynchocephala*).—The only existing member of this order is the little New Zealand Tuatara (*Hatteria punctata*, see vol. i, p. 236). Its tail resembles that of a crocodile, and can be used on occasion as a swimming organ.

Fig. 625.—Leathery Turtle (*Dermatochelys coriacea*) swimming (much reduced)

BIRDS (AVES) AS SWIMMERS

A great many Birds are either semi-aquatic or aquatic in habit, and exhibit a series of adaptations to life in the water which are even more interesting than those presented by the Tortoises and Turtles among Reptiles. We have elsewhere seen (vol. ii, p. 426) that the breathing arrangements of Birds are extremely perfect, in relation to the unusually high temperature of the blood (from 103°–104° F.), and there are several devices by which aquatic birds are prevented from being unduly chilled by partial or complete immersion in water. For one thing, the plumage is very thick and extremely oily, so that the current saying about water falling off a duck's back is founded on fact. It is indeed characteristic of such forms that the oil-gland which opens on

the upper side of the tail-region should be extremely large, and the greasy matter secreted by it is used for lubricating the feathers. These consequently do not get wet, and the water is unable to displace the air which they entangle, so that the actual surface of the skin is kept dry and warm. We find, too, in water-birds a considerable accumulation of fat below the skin, forming a non-conducting layer which goes far to prevent loss of heat from the outside of the body.

For the purpose of the present section it is convenient to draw a distinction between birds which swim entirely or mostly at the surface, and those which are more or less expert at swimming under water and diving. But it must, of course, be understood that the division is purely an artificial one, as all gradations may be traced between the two habits.

SURFACE-SWIMMING BIRDS

The small specific gravity of a Bird's body, due to the presence of extensive air-sacs connected with the lungs (see vol. ii, p. 426), is clearly an advantage in surface-swimming. We should expect, on the same principle, to find the bones of surface-swimmers richly provided with air-cavities, as is the case with a great many land-birds. But in many instances, *e.g.* Gulls, the bones are filled with marrow, as in amphibians, reptiles, mammals, diving birds, and many land birds. Lightness is clearly not the only thing to be considered, but our knowledge is at present too imperfect to explain all the facts in this particular case.

Fig. 626.—Herring Gull (*Larus argentatus*)

Typical Gulls (*Larus*) (fig. 626) may be taken as good

average examples of surface-swimmers, using their legs as paddles, of which the efficiency is greatly increased by the presence of webs between the three forwardly-directed toes. The inner or great toe (*hallux*) can be of little use for swimming, for it is small, backwardly directed, and shifted up a little, so as not to touch the ground when the bird is standing. The feet are used alternately during swimming, and, as in all limbs so modified, they present a minimum surface when being drawn forwards, but are spread out to their full extent during the powerful backward stroke.

Ordinary SURFACE DUCKS, as they may be called to distinguish them from their diving cousins, include a number of well-

Fig. 627.—Sheld-Drakes (*Tadorna cornuta*)

known species, such as the Wild Duck (*Anas boschas*), Sheld-Drake (*Tadorna cornuta*) (fig. 627), Teal (*Querquedula crecca*), and Widgeon (*Mareca penelope*). These are more specialized in some respects than Gulls, as a result of still further adaptation to the aquatic habit. The plumage is particularly dense and oily, and the shape of the body is almost boat-like. Although the legs and feet (fig. 628) are much like those of gulls, they are a good deal shorter, and set on much farther back. Though this is no doubt conducive to rapid swimming, it is at the expense of walking power, and is the cause of the ungraceful "waddle" which distinguishes ducks on land. During swimming the two legs are pushed back almost but not quite at the same time. The remarks just made about ordinary surface ducks applies with equal force to the closely related Swans.

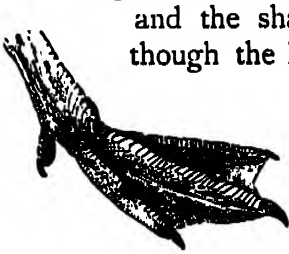


Fig. 628.—Foot of a Duck (*Anas boschas*)

BIRDS WHICH SWIM UNDER WATER AND DIVE

We have now to consider birds which are more perfectly adapted to an aquatic life than the surface swimmers, and which spend more or less of their time actually submerged in water. In such cases the plumage is markedly dense and oily, the general shape of the body is comparable to a rounded wedge suited for cleaving the water, and the legs are more specialized as paddles than those of ordinary Ducks and Swans, while at the same time they are set on even further back, till in the most extreme cases walking on land is effected in a very clumsy way. It becomes a matter of importance that the specific gravity of the body should be reduced as far as possible, for though lightness is an obvious advantage for purposes of flight, it clearly handicaps a diving animal. It is not, therefore, surprising to find that in diving birds all or most of the bones are solid, *i.e.* free from the air-spaces that are in so many other cases highly characteristic.

Although we can speak in general terms of birds less adapted or more adapted to diving and swimming under water, it is not possible to include them all in a single series, for different groups have specialized in somewhat different ways and along various lines. It will therefore be convenient to consider these groups separately.

Closely related to Surface Ducks and Swans are to be found a number of forms which may be termed collectively DIVING DUCKS, sometimes also called Sea Ducks, because the large majority of them are essentially marine. As in Surface Ducks, the feet are the swimming organs, but are here somewhat more specialized, for the great toe is bordered by a well-marked flap of skin, and thus increases the surface presented to the water. It may also be noted that the legs are set on further back than in surface forms, while the body is somewhat narrower from side to side. There is, in fact, as regards general shape, the same sort of difference between a surface-swimming bird and a diving bird as that between a life-boat and a submarine. Common examples of the present group are the Eider Duck (*Somateria mollissima*) (fig. 629), the Pochard (*Fuligula ferina*), the Canvas-back (*F. Vallisneria*) of North America, and the Logger-head

or Steamer Duck (*Tachyeres cinereus*) of Chili. All these forms progress clumsily on land, and their heads are somewhat wedge-shaped. Even when swimming at the surface the body is more

Fig. 629.—Eider Duck (*Somateria mollissima*)

deeply sunk than in ordinary ducks, a peculiarity that is probably associated with the power of expelling some of the air in the air-sacs, thus reducing the specific gravity of the body. Increased

Fig. 630.—1, Red-breasted Merganser (*Mergus serrator*) and 2, Black throated Diver (*Colymbus arcticus*)

diving power is commonly associated with reduced powers of flying as well as of walking. In these particular birds the wings are short, and flight, though it may be powerful, is more or less slow and heavy. In the Steamer Ducks it is said that the adults are unable to fly at all.

Mergansers (fig. 630) are closely related to the Diving

Ducks, but their bills are much longer and narrower. The two commonest British species are the Red-breasted Merganser (*Mergus serrator*) and the Goosander (*M. merganser*). These birds are very expert divers and swimmers, and it would seem that they are able to regulate the amount of air in the air-sacs, for they can either float high on the water, swim with only the head and neck projecting above the surface, or propel themselves at a great rate when completely submerged. In reference to a flock of Red-breasted Mergansers Macgillivray remarks (in *A History of British Birds*):—"The birds seemed to move

Fig. 631.—The Coot (*Fulica atra*), and its lobed foot drawn to a larger scale

under the water with almost as much velocity as in the air, and often rose to breathe at a distance of 200 yards from the spot at which they had dived".

Some of the RAILS (*Grallæ*) are of thoroughly aquatic habit, and of these may be mentioned among British forms the Moor-Hen or Water-Hen (*Gallinula chloropus*) and the Coot (*Fulica atra*) (fig. 631). The former bird possesses long toes that are not webbed, but are fringed with a narrow membrane, which increases their purchase upon the water. It is interesting that in an allied form, native to the southern parts of Australia, Mortier's Water-Hen (*Tribonyx Mortieri*), the toes are devoid of even this amount of extension, and, as might be expected, the powers of swimming and diving are feebler. The Coot, on the other hand,

swims and dives with greater facility than the Water-Hen, and this is related to the fact that the three front toes are provided with broad folds of skin at the sides, so that they present a large surface to the water. It is also stated that these lobate toes are of use in enabling the bird to move rapidly over water-lilies and other floating plants.

CORMORANTS, &c. (*Steganopodes*).—The members of this group, though powerful swimmers, and often expert swimmers, have not sacrificed to any great degree their powers of flight, and some of them are pre-eminent in this respect. As in most other aquatic birds, however, their legs are set on rather far back, which renders the gait on land somewhat clumsy, though it is undoubtedly a great aid to swimming. The feet are more specialized than in any of the cases so far considered, for they are fully webbed, *i.e.* membranous expansions stretch between all four toes, the great toe included (fig. 633). These organs are therefore paddles of unusual power, and are used simultaneously, like the legs of a frog.

Probably the worst swimmers of this order are to be found in the Frigate Birds (*Fregatus*) and Tropic Birds (*Phaëthon*), both of which are thoroughly oceanic, being found in the open sea at great distances from land. As flying birds they are pre-eminent, and it is interesting to notice that the feet of the Frigate Birds differ from those of other members of the order in being less fully webbed. In fact the toes are united together for only about half their length. Pelicans both swim and dive, keeping for the most part to estuaries, rivers, and lakes. The diving powers, however, are not very great, except in the American White Pelican (*Pelecanus trachyrhynchus*). Here, as in all the members of the order except Tropic Birds, the nostrils are almost covered over by a membrane, an arrangement which is clearly advantageous when the head is frequently under water.

Gannets are well-known oceanic birds, of which the Common Gannet or Solan Goose (*Sula Bassana*) (fig. 632) breeds on the Bass Rock, on Ailsa Craig, and in a few other British localities. It is remarkable for the habit of diving from a great height in order to secure its prey. In this case a "flying start" is especially necessary, for the bones are hollow to an unusual extent, and air-sacs are found even under the skin. It has been suggested that these last act like an air-cushion to break the force of

impact with the water. The birds known to sailors as "boobies" are of the Gannet kind.

The cosmopolitan Cormorants are the best swimmers and divers of their order, and it is not therefore surprising to find that their wings are shorter and their legs set further back than

Fig. 632.—Gannets (*Sula Bassana*)

in the other related forms. We have two native species, the Black Cormorant (*Phalacrocorax carbo*) (fig. 633) and the smaller Green Cormorant or Shag (*P. graculus*), both of which are essentially coast forms, though some foreign kinds frequent rivers and lakes. These birds can dive quite well from the floating position, and the shape of their bodies is admirably suited for cleaving the water, besides which they are known to be able to expel a large amount of air from their air-sacs, thus rendering

themselves more weighty. Regarding the Green Cormorant Headley remarks (in *The Structure and Life of Birds*):— "Among the diving birds at the Zoological Gardens there is frequently a Shag, and as he chases the fish in the tank, he holds his wings motionless, just slightly lifted from the body. . . . Some birds dive to great depths. The Shag begins by jumping up in the water and taking a header, then he strikes hard up-

Fig. 633 – Black Cormorant (*Phalacrocorax carbo*)

ward. One was caught once in a crab-pot 20 fathoms below the surface."

The Darters or Snake-Birds (*Plotus*) (see vol. ii, p. 49) are river cormorants, which both fly and swim in much the same way as the forms just described. They often swim with only the head and long sinuous neck above the surface, presenting the appearance which has probably earned for them the name of "snake" birds.

Grebes, Divers, and Auks (*Pygopodes*) make up a group of birds distinguished by their great powers of swimming and diving. All of them exhibit in a greater or lesser degree the graceful curved outline associated with easy progression under water.

The short legs are set on exceedingly far back, and the feet are either much like those of a duck, or the three front toes are lobate, as in the Coot (p. 62). The wings are relatively short, and many of the species rely chiefly on diving when they are pursued.

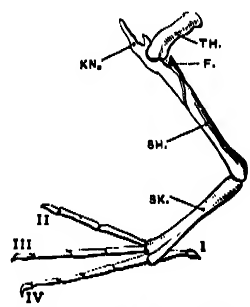


Fig. 634.—Bones of a Diver's Leg (reduced)

TH., Thigh-bone; KN., knee-cap; SH., shin-bone; F., fibula; SK., shank-bone; I–IV, toes.

Grebes and Divers agree in the possession of one or two interesting anatomical features related to their habits. A small great toe is present, and is fringed by membrane, while the shank is extremely flat, presenting a broad surface to the water during the effective backward stroke, but a narrow cut-water edge while being drawn forward again. The knee-cap and upper end of the shin-bone are drawn out into a sort of spike, which affords considerable purchase to some of the swimming muscles which are attached to it (fig. 634). In Grebes the long front toes are broadly lobed, presenting a considerable surface to the water

Fig. 635.—Little Grebe (*Podiciþes fluviatilis*), and its broadly-lobed foot drawn to a larger scale

when fully expanded as they are thrust back, but folding up to small compass when moved in the other direction. The tail is exceedingly short. These are freshwater forms, of which we have one well-known species in Britain, the Little Grebe or

Dabchick (*Podicipes fluviatilis*) (fig. 635). Divers differ from Grebes in several respects, among which may be mentioned the presence of complete webs between the three front toes, somewhat longer wings, and a rather better developed tail. They are essentially marine in habit, but resort to inland waters during the nesting season. Our commonest native species is the Red-throated Diver (*Colymbus septentrionalis*). The Black-throated Diver (*C. arcticus*) (fig. 630) is much more rarely seen.

Auks are here associated with Divers and Grebes in accordance with the common practice, but they are now often assigned

Fig. 636.—Razor-Bill (*Alca torda*)

to a distinct order, supposed to be most nearly related to Gulls. Their feet are pretty much like those of Divers, except that the great toe is either absent or extremely small. The shank and shin-bone do not exhibit the peculiarities described above for Divers and Grebes. Although the wings are short, the power of flight has not been lost in existing species, though the extinct Great Auk or Gare-Fowl (*Alca impennis*) was flightless (see vol. i, p. 183). Our commonest British species are the Razor-Bill (*Alca torda*) (fig. 636), the Guillemot (*Uria troile*), and the Puffin (*Fratercula arctica*). The most interesting point about the Auks is that they swim under water chiefly by means of their wings, while the webbed feet are used as rudders. In this sort of submarine flight the Great Auk appears to have excelled the forms now living.

Penguins (*Impennes*).—Although these extraordinary birds,

which have entirely lost the power of flight, are not unlike the Great Auk in appearance (indeed this bird was popularly called a "penguin"), this does not imply close relationship, but is the outcome of adaptation along similar lines to thoroughly aquatic habits. These birds are indeed more closely related to the Divers and Grebes, agreeing with the former in the structure of the feet and the flatness of the shank. The wings have been modified into stiff paddles or flippers, which are the chief propulsive organs, as the feet would appear to be mainly used for steering purposes. They are covered with short, almost scale-like feathers, and are, so to speak, twisted round, so as to give a very effective backward stroke, whereas in the wing of an ordinary flying-bird the downward movement is naturally the best marked. Penguins are characteristic of the southern hemisphere, the largest species being the Emperor Penguin (*Aptenodytes Forsteri*), native to Victoria Land and the neighbouring ocean area, and reaching the length of 3 feet. The smallest member of the order is the Blue Penguin (*Spheniscus minor*), which attains a length of 19 inches, and is found in the New Zealand and South Australian areas (fig. 637).

Fig. 637.—Blue Penguins (*Spheniscus minor*)

MAMMALS (MAMMALIA) AS SWIMMERS

Unlike Man, the great majority of Mammals are able to swim without difficulty for a greater or less distance when for the first time they enter or fall into the water. The facts are thus very clearly put by Pettigrew (in *Animal Locomotion*):—"Man, in order to swim, must learn the art of swimming. He must serve a longer or shorter apprenticeship to a new form of locomotion, and acquire a new order of movements. It is otherwise with the majority of animals. Almost all quadrupeds can swim the first time they are immersed, as may readily be ascertained by throwing a newly-born kitten or puppy into the water. The same may be said of the greater number of birds. This is accounted for by the fact that quadrupeds and birds are lighter, bulk for bulk, than water, but more especially, because in walking and running the movements made by their extremities are precisely those made in swimming. They have nothing to learn, as it were. They are buoyant naturally, and if they move their limbs at all, which they do instinctively, they swim of necessity. It is different with man. The movements made by him in walking and running are not those made by him in swimming; neither is the position resorted to in swimming that which characterizes him on land." All this is illustrated by a man who "swims like a dog", to use a well-known technicality, for he then imitates a quadruped and walks on all-fours through the water.

ADAPTATIONS TO SWIMMING EXHIBITED BY MAMMALS

It will be clear from what has been said that ordinary land Mammals are able to swim on occasion without being specialized for the purpose, and with these we have here no further concern. There are, however, many species which are more or less aquatic in habit, and such forms present, at least in most cases, obvious peculiarities which are clearly to be regarded as adaptations to the mode of life, and many of which are necessarily of the same nature as those already described in other classes of backboned animals.

We find, in the first place, that as regards shape the body of an aquatic mammal is more or less suitable for moving through the water with a small amount of friction, and the same end is

furthered by the compact nature of the fur, or it may be by the reduction or even complete suppression of the hairy covering of the body. The external ear-flaps are commonly reduced in size, or perhaps absent altogether, while auditory apertures and nostrils are frequently valvular, so as to prevent free entry of water. Should the tail be used for swimming or even for steering, it will be found well developed and flattened either from side to

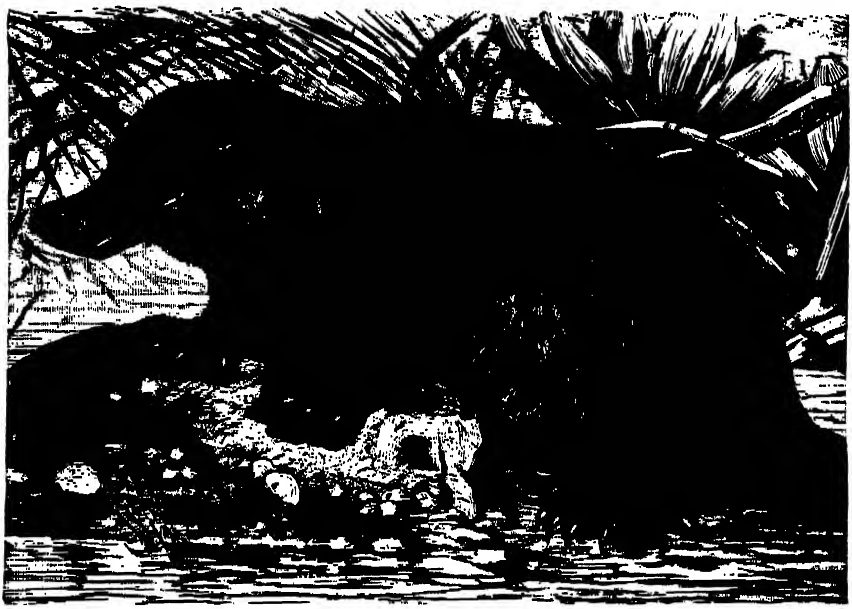


Fig. 638.—Duck-Mole (*Ornithorhynchus paradoxus*)

side, or from above downwards. And the limbs are typically modified in shape and sometimes position for propulsive purposes, very much on the same lines as in some aquatic reptiles (see p. 55). In extreme cases the hind limbs are absent altogether, a character which is correlated with the presence of a swimming-tail of exceptional efficiency. As in Birds, the same ends may be attained in somewhat different ways in different orders, and it is therefore best to consider such groups separately, ending with those where specialization is at a maximum.

Egg-laying Mammals (*Monotremata*).—One member of this primitive Australian group, the Duck-Mole (*Ornithorhynchus*) (fig. 638), is eminently aquatic in habit, presenting in this respect a strong contrast to its cousin, the Spiny Ant-Eater (*Echidna*). The body is flattened from above downwards, as also is the tail,

and the fur is dense and closely set. Behind the small eyes no trace of ear-flaps is to be seen, and the auditory apertures are valvular. Both fore- and hind-limbs are short and webbed, the webs of the former being particularly well developed, and, when in use, extending beyond the claws. Swimming is chiefly effected by these paddle-like limbs, especially the front ones, but in diving the flat tail is used for both propelling and steering. Duck-Moles haunt the quiet reaches of streams in South Australia and Tasmania, living in long burrows, the openings of which are under the surface of the water. The feeding habits are correlated with the aquatic mode of life, and resemble those of ducks. There is indeed a striking resemblance between the snout of a Duck-Mole and the bill of a Duck, which is the outcome of specialization along similar lines.

Fig. 639.—Water Opossum (*Cheironectes variegatus*)

Pouched Mammals (*Marsupials*).—The only species belonging to this multifarious group requiring notice here is the Water Opossum (*Cheironectes variegatus*) of South America, which lives on the banks of rivers, upon the fishes of which it preys. Although an expert swimmer, it is not modified to nearly the same extent as the Duck-Mole in relation to the aquatic habit. But the fur is dense and short, and the hind-feet webbed, while the long scaly tail is not unlike that of an Otter (fig. 639).

INSECT-EATING MAMMALS (*Insectivora*).—Several animals included in this widely-distributed and somewhat lowly order are more or less specialized to fit them for an aquatic or semi-aquatic life.

Shrews.—The least-modified swimming Insectivore is one of our native forms, the Water-Shrew (*Crossopus fodiens*), which is a good deal larger than its non-aquatic relatives. Its fur is dense and not easily wetted, the long tail is somewhat flattened from side to side, and though the feet are not webbed, they are provided on their outer sides with stiff bristles which give an increased surface for application to the water. The movements of this species are thus described by Bell (in *British Quadrupeds*):—"Its swimming is principally effected by the alternate action of the hinder feet, which produces an unequal or wriggling motion. It makes its way, however, with great velocity, and as it swims rather superficially, with the belly flattened, the sides, as it were, spread out, and the tail extended backwards as a rudder, it forms a very beautiful and pleasing object, moving on the calm surface of a quiet brook, or diving in an instant after its food, its black velvety coat becoming beautifully silvered with the innumerable bubbles of air that cover it when submerged; and on rising again the fur is observed to be perfectly dry, repelling the water as completely as the feathers of the water-fowl. When submerged the ear is nearly closed by means of three little valves."

The Himalayan Swimming-Shrew (*Chimarrogale Himalayica*), and an allied Japanese species, closely resemble the Water-Shrew in structure and habits. But it is very interesting to note that an Insectivore native to Thibet, the Web-footed Shrew (*Nectogale elegans*), is more completely adapted to an aquatic life. In this case ear-flaps are entirely absent, and the feet are webbed.

The *Desmans* or *Divers* are aquatic Insectivores allied to Moles, which they somewhat resemble in the texture of their fur and in general appearance, though their tails are very much longer, and the feet quite different in structure. They are often termed Musk-Shrews (a name more properly applied to a group of land-shrews), but "Water-Moles" would be a better descriptive term. Of the two existing species the larger is the Wuychuchol or Russian Desman (*Myogale moschata*), and this is seen at a glance to be adapted to an aquatic life (fig. 640). The feet are not only

fringed with strong bristles, as in a Water-Shrew, but are also fully webbed, and the powerful tail, laterally flattened and margined with stiff hairs, is evidently a swimming organ. The long bare narrow snout bears the nostrils at its tip, and is not only used for finding and seizing food, but is also of use in enabling the animal to breathe when under water, for its tip can readily be protruded above the surface. The smaller Spanish Desman (*Myogale Pyrenaica*), native to the streams of northern Spain, is not so highly specialized as its Russian cousin, for its tail is cylindrical instead of being flattened.

Fig. 640.—Russian Desman (*Myogale moschata*)

The largest known Insectivore is a remarkable otter-like creature (*Potamogale velox*), which lives in the rivers of West Africa. It is the type of a distinct family. The feet are not webbed, but the powerful flattened tail is a very efficient swimming organ, and passes gradually into the body instead of being sharply marked off. The animal is about 22 inches long, of which half is taken up by the tail.

Gnawing Animals (*Rodentia*).—A number of adaptations to an aquatic mode of life are exemplified by various species of this cosmopolitan order. All the swimming forms possess collar-bones, and the largest Rodents, like the largest Insectivores, inhabit the water. Some possess swimming feet, others swimming tails, and this furnishes a further parallel character of the two orders.

Voles.—The familiar water-"rat" of Britain, or, to speak more accurately, Water-Vole (*Microtus amphibius*), is an admirable swimmer and diver, though but little modified for the purpose, for its feet are not webbed, and its tail is not flattened, though, unlike that of an ordinary rat, it is hairy instead of scaly, thus presenting a fairly large surface to the water. The ears are short and rounded, but this can hardly be looked upon as

Fig. 641.—Musk-Rat (*Fiber zibethicus*)

a special aquatic character, as it is also found in land-voles, which very likely acquired it as an adaptation to burrowing. The Musk-Rat or Musquash (*Fiber zibethicus*) of Canada may be regarded as a large vole exhibiting marked aquatic specialization (fig. 641). Both fore- and hind-feet are furnished with hairy webs, while the tail is markedly flattened from side to side, and its edges are fringed with stiff hairs, as in so many other similar cases.

Beavers.—The Beaver (*Castor fiber*) is among the largest of its order, for the weight may be 60 pounds or more, and the length over 3 feet, of which nearly one-third is taken up by the tail. Of eminently aquatic habit, this creature presents numerous characters correlated to this particular mode of life. Not only is the general

shape of the body well suited for cleaving the water, but the fur is unusually dense, the hind-feet are webbed, and the strong scaly tail is remarkably broad, being flattened from above downwards. During the act of diving eyes, ear-passages, and nose-cavities are all carefully guarded. For the eyes are small and provided with third eyelids (nictitating membranes), which can be pulled over them curtain-wise, yet without unduly obstructing vision; the valvular nostrils can readily be closed; and the small ear-flaps can be folded over the passages they adjoin, so as to effectively keep out water. The absence of webs between the toes of the fore-feet is readily understood, for these extremities are used in many delicate carpentry operations, during which it is clearly advantageous for the toes to be quite free. Although the webbed hind-feet are of great importance in swimming, the tail is the chief agent of propulsion in the water, and at first sight it seems curious that it should be flattened at right angles to the more usual direction of compression. But it appears that this organ can not only be moved up and down in a way which must be effective for diving purposes, but can also be twisted round so as to deliver side-strokes with its broad upper and lower surfaces. It acts, in fact, like a screw-propeller, but is not specially remarkable in this respect, since the same thing is true for most swimming and flying organs.

Coypus and Capybaras.—The last two examples of swimming Rodents will be taken from among the forms which inhabit South America, the head-quarters of the order. The Coypu (*Myopotamus coypu*) is particularly common in the Plate River and its tributaries, and from its appearance is often known as the "Plate Beaver". It is, however, much less specialized than its namesake, for though the hind-feet are webbed, the long hairy tail is not flattened. Though an excellent swimmer, it is asserted that the Coypu is a bad diver. It is at home in salt water as well as in fresh, an example of this being afforded by the numerous individuals which live on the shores of the Chonos Islands, in the south of Chili.

The Capybara or Carpincho (*Hydrochærus capybara*) is characteristic of South American rivers from Guiana to the Argentine Republic, and may be regarded as a huge guinea-pig, resembling its small relative in general appearance, practical absence of a tail, and the presence of little hoofs on its digits

(fig. 642). It can both swim and dive with great facility, by means of its short strong limbs. Webs stretch between the toes, of which the fore-feet possess four and the hind-feet only three. Although mainly a freshwater animal, the Capybara is also found in the estuary of the Plate River. It is the largest existing Rodent, comparable in size to a yearling pig, and attaining a length of 4 feet and a weight of about 1 cwt.

FLESH-EATING MAMMALS (*Carnivora*).—These are divided into the two great groups of Land Carnivores (*Fissipedia*) and Aquatic

Fig. 642.—Capybara (*Hydrochærus capybara*)

Carnivores (*Pinnipedia*). Among the former Otters are specialized swimmers, and some few other forms are more or less modified for the purpose. Pinnipedes, including Sea-Lions, Walruses, and Seals, are altogether adapted to an aquatic life.

AQUATIC FISSIPEDES

Some of the terrestrial beasts of prey seek their food in the water, without exhibiting any noticeable features specially related to swimming or diving. Among these may be mentioned the Fishing Cat (*Felis viverrina*) of India and the Polar Bear (*Ursus maritimus*). The habits of the former are imperfectly known

though it undoubtedly feeds on fish, and almost certainly pursues them in the water, as domesticated cats have been occasionally known to do. Polar Bears can swim and dive with great facility, and it is not impossible that the great breadth of their paws may in part be an adaptation to this habit, though primarily related to walking in plantigrade fashion, *i.e.* on the palms of the hands and soles of the feet. At any rate this great breadth must be of considerable assistance in swimming.

Visons, Otters, and Sea-Otters.—The Visons, or Minks, well known as fur-yielding forms, are native to the arctic and north temperate regions, where they spend a large part of their time in the pursuit of fishes, frogs, &c., in rivers and lakes. Three ill-defined species are known, the European Vison (*Mustela lutreola*), the Siberian Vison (*M. Sibirica*), and the American Vison (*M. vison*), inhabiting respectively the continents indicated by their names. These creatures are in effect water-polecats, and as regards both structure and habits are intermediate in character between creatures of the Weasel kind and Otters. Their feet are partly webbed, and are the chief swimming organs, but the large bushy tail probably serves as a rudder.

Otters.—The Common Otter (*Lutra vulgaris*) will serve as a type of this thoroughly aquatic group of Carnivores, which are not unlike Visons, but are more highly specialized (see vol. ii, p. 22). The cylindrical body presents a continuous curved outline, from the rounded head to the long tail, which is somewhat flattened from above downwards. As in some of the other types already described, the nostrils are valvular, the eyes small, and the ear-flaps much reduced, while the apertures of the ears can be closed at will. Both fore- and hind-limbs are remarkably short and strong, while the toes are fully webbed. The broadened extremities are the chief propulsive organs, the tail mainly serving as a rudder. Otters sometimes swim at the surface, but more commonly entirely submerged, and can make good headway against strong currents. The fur is extremely dense and smooth, serving the double purpose of preventing chill and reducing friction during swimming. Haacke (in *Das Thierleben der Erde*) says that the coat "takes up but little moisture, even if the animal remains for hours in the water, a characteristic which at once disappears in a dead or severely wounded otter. This results from the extraordinary quantity of electricity which is stored up

in the coat of uninjured living individuals, but not in that of a dead or wounded one."

The Sea Otter (*Latax lutris*) of the North Pacific is more profoundly modified in relation to an aquatic life than its fresh-water cousins, and presents some features which are still further emphasized in Sea-Lions. The head is much rounder than that

Fig. 643.—Sea-Otter (*Latax lutris*)

of an Otter, the flattened tail much shorter, and the hind-limbs set on much further back (fig. 643). The hind-feet are very much larger than those in front, and constitute powerful flippers which do most of the work in swimming.

PINNIPEDE CARNIVORES

These are all highly-specialized aquatic forms, of which there are three groups, Eared Seals, Walruses, and Seals. In all cases the openings of the nose and ears are valvular, and there is a thick layer of fat below the skin. The limbs are modified into flippers.

Eared Seals (*Otaridæ*) include those forms popularly known as Fur-Seals, Sea-Lions, and Sea-Bears, which possess a very small ear-flap, an appendage entirely absent in the other Pinni-

pedes (fig. 644). The body is spindle-shaped, but the neck region is fairly distinct, while the tail is a mere stump. Both fore- and hind-limbs are converted into flippers, and the latter, though set on very far back, can be turned forwards under the body to assist in progression on land. Strong webs are developed between the digits, and project beyond the tips of these,

Fig. 644.—Pinnipedes. 1, Eared Seals (*Otaria*). 2, Common Seal (*Phoca*)

ending in a sort of scalloped edge with a lobe opposite the of each of them. The claws are reduced in size, and those of the external digits in the hind-limb are absent altogether. Swimming is effected chiefly by means of the front flippers, which are almost comparable in shape to the wings of a penguin, this being largely due to the fact that the first or inner digit is the longest, while the others exhibit a gradual diminution in size (see fig. 645). The hind-flippers mainly serve for steering, and the inner and

outer digits (first and fifth) are larger than the other three. Regarding the nature of the swimming movements of the Behring Sea Fur-Seal or Sea-Bear (*Otaria ursina*), Elliott writes as follows (in *An Arctic Province*):—"They all swim rapidly, with the exception of the pups, and may be said to dart under the water with the velocity of a bird on the wing. As they swim they are invariably submerged, running along horizontally about two or three feet below the surface, guiding their course with the hind-flippers as by an oar, and propelling themselves solely

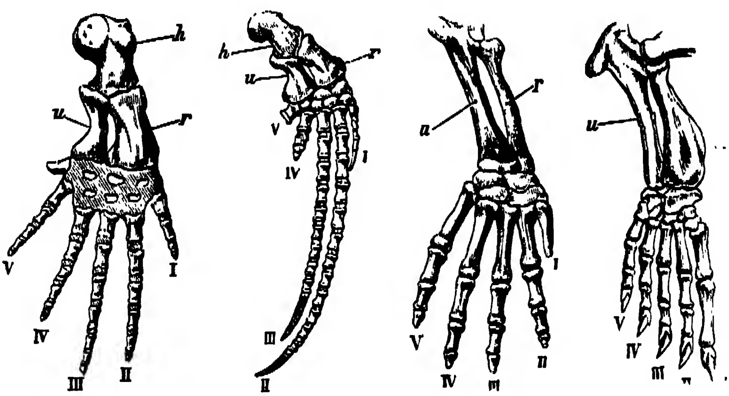


Fig. 645.—Skeleton of the Fore-limb or Flipper of the Whalebone Whale. Same of the Caaing Whale. Same of the Dugong. Same of the Seal

r, Radius; *u*, Ulna; *h*, Humerus; I–V, Digits.

by the fore-feet, rising to breathe at intervals which are either very frequent or else so wide apart that it is impossible to see the speeding animal when he rises a second time. . . . In all their swimming which I have had a chance to study, as they passed under the water, mirrored to my eyes from the bluff above by the whitish-coloured rocks below the rookery waters at Great Eastern Rookery, I have not been able to satisfy myself how they used their long, flexible hind-feet, other than as steering media. If these posterior members have any perceptible motion, it is so rapid that my eye is not quick enough to catch it; but the fore-flippers, however, can be most distinctly seen as they work in feathering forward and sweeping flatly back, opposed to the water, with great rapidity and energy."

Walruses (*Trichechidæ*).—The Walrus (*Trichechus rosmarus*) is bulkier and clumsier than any of the Eared Seals, and differs from them in many particulars (fig. 646). Leaving the teeth out

of consideration (see vol. ii, p. 25), attention may be directed to the length of the head, the smallness of the eyes, and the complete absence of ear-flaps, while the neck is less well marked, and the hairy covering of the body not so well developed. In old individuals the skin is more or less bare, but its extreme thickness compensates for this. The limbs correspond pretty closely to those of a sea-lion, but are more enclosed, as it were, in the skin of the trunk, and blunt claws are present on all the digits.

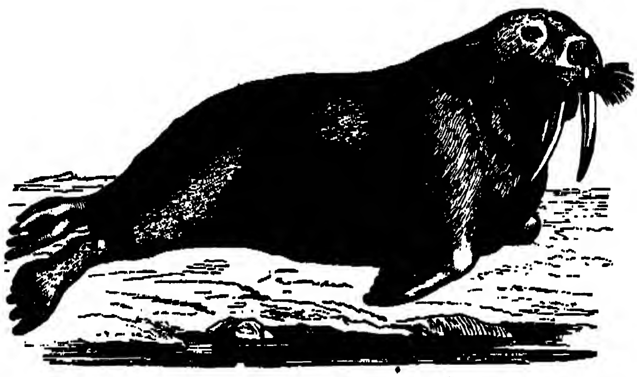


Fig. 646.—Walrus (*Trichechus rosmarus*)

The front-flippers are used during swimming as in Sea-Lions, &c., but propulsion is also aided by the hind-flippers, which are actively moved from side to side, something like the tail of a fish. In spite of this, however, the Walrus swims neither so rapidly nor so gracefully as its eared relatives, for the shape of its body is not so well adapted to progression in the water, though its powers in this direction are of no mean order.

Seals Proper, or Earless Seals (*Phocidæ*) (fig. 644).—Of all Pinnipedes these are best adapted to the conditions of a thoroughly aquatic life, and it is not therefore surprising to find that they are more fish-shaped than either Eared Seals or Walruses, the head passing gradually into the trunk, owing to the absence of a clearly-marked neck. The front-flippers (fig. 644) are smaller than the hind ones, which are directed backwards, and so enclosed in the skin of the hinder part of the body that they cannot be turned forwards, as in a Sea-Lion or Walrus, to aid progression on land or ice. The webs do not extend beyond the tips of the digits, all of which are armed with claws. We have seen that the hind-flippers of a Walrus act to some extent

like the tail of a fish, and this is true to a much greater extent of the corresponding organs in a Seal. Pettigrew (in *Animal Locomotion*) speaks as follows of the mode of swimming:—" It would appear that the swimming appliances of the seals (where the feet open and close as in swimming-birds) are to those of the sea-mammals generally what the feathers of the bird's wing (these also open and close in flight) are to the continuous membrane forming the wing of the insect and bat. The anterior extremities or flippers of the seal are not engaged in swimming, but only in balancing and in changing position. When so employed the fore-feet open and close, though not to the same extent as the hind ones; the resistance and non-resistance necessary being secured by a partial rotation and *tilting of the flippers. By this twisting and untwisting the narrow edges and broader portions of the flippers are applied to the water alternately.* The rotating and tilting of the anterior and posterior extremities, and the opening and closing of the hands and feet in the balancing and swimming of the seal, form a series of strictly progressive and very graceful movements. They are, however, performed so rapidly, and glide into each other so perfectly, as to render an analysis of them exceedingly difficult."

There can be no doubt that Pinnipedes are the specialized descendants of land carnivores, and we know that the group is a very ancient one. Unfortunately the geological evidence is too scanty to enable us to trace its evolution, though there is some ground for thinking that the adaptations to an aquatic life were first acquired in lakes, migration to the sea afterwards taking place.

SEA-COWS (*Sirenia*).—This small group of animals, which at the present time only includes Manatees and Dugongs, is not improbably an offshoot from the order of Hoofed Mammals (*Ungulata*), although there is an unfortunate lack of evidence on the subject. These creatures live in shallow coastal waters, estuaries, and certain large rivers (see vol. i, p. 101). The somewhat spindle-shaped body is flattened from above downwards, and there is a distinct neck. As in Seals, a deposit of fat underlies the thick skin, which, however, is but sparsely covered with hair. The fore-limbs are flippers, capable of movement both at the shoulder and elbow, but claws are either absent altogether (Dugong) or reduced to a few vestiges (Mana-

tee). Hind-limbs are absent altogether, though traces are to be found by dissection, and the work done by these members in a Seal is here effected by a broad swimming-tail, rounded in the Manatee (fig. 647), and shaped like that of a bony fish in the Dugong (see vol. ii, p. 174). But the tail of a fish is flattened from side to side, that of a Sea-Cow from above downwards, a condition found in some of the swimming mammals already described, as *e.g.* in the Beaver (see p. 74). Though the main direction of movement for this organ appears to be up and

Fig. 647.—American Manatee (*Manatus Americanus*)

down, it can doubtless be twisted to some extent so as to act sideways upon the surrounding water, in the manner already described for the Beaver (see p. 74). Swimming is furthered by the comparative flexibility of the hinder part of the body as compared with a mammal where hind-limbs are present. For in such cases these limbs are united to a region of the backbone (*sacrum*) in which some of the constituent bones have fused together. In Sea-Cows the disappearance of the hind-limbs has involved the doing away with this fusion as no longer necessary. Hence a proportionate gain in flexibility. But neither the Manatee nor the Dugong can compare in swimming powers with Sea-Lions, Walruses, or ordinary Seals. The fact that vestiges of hind-limbs are still present, though they do not project externally, is enough in itself to prove that these members were

present in remote ancestral forms, and it is particularly interesting to find that in a long since extinct fossil form (*Halitherium*) the remains of such limbs were rather better developed, though still insignificant and entirely sunk within the body.

WHALES, PORPOISES, &c. (*Cetacea*).—Of all aquatic mammals these are the most profoundly modified to fit them for life in water, and they have evolved on much the same lines as Sea-Cows, though to a very much greater extent. The general outline of the spindle-shaped body is so like that of a fish (fig. 648), that many uneducated persons imagine Whales to be simply huge

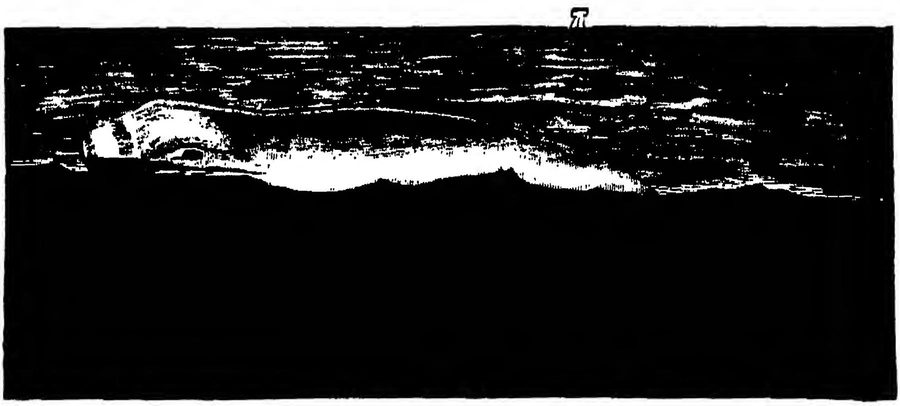


Fig. 648.—White Whale (*Delphinapterus leucas*)

fishes of peculiar kind, and this error is perpetuated by the term whale-"fisheries", which we still employ together with, it may be noted, the expression seal-"fishery", for which there is even less excuse. The body of any one of these animals is somewhat flattened from side to side, just the opposite to what is found in Sea-Cows, and presents a continuous curve from side to side. As in the case of the best endowed swimmers among fishes (see p. 43), the curve is precisely that which expert marine engineers tell us is most suitable for cleaving water with the least amount of friction. Such a shape could not be attained without a practical absence of neck, and of this we accordingly find no trace visible externally. This region can, however, be identified in the skeleton, though it has undergone remarkable compression, not being more than a foot long even in the largest Whales. Nevertheless seven bones (*vertebræ*) enter into its composition, the typical number for Mammals (see vol. i, p. 66), though these

bones are partly or entirely fused together. It is certainly a remarkable instance of adherence to a common plan of structure that the short-necked Whale and the long-necked Giraffe should have precisely the same number of bones supporting that region. The exceptions to this rule are so few that it may be of interest to note in passing that there are only *six* bones in the neck of a Dugong.

The hinder end of a Cetacean's body is terminated by a horizontally-flattened tail, comparable to that of a Dugong, for it is deeply notched and prolonged on either side into a triangular lobe or "fluke". In many cases, too, there is a triangular "fin" on the back, but fin and flukes alike are of fibrous texture, and are not supported by the firm rods or "fin-rays" characteristic of fishes (vol. i, p. 261). The fore-limbs are entirely converted into paddles which serve for steering and balancing, and though they usually possess five digits, these are not to be distinguished externally, and there is an entire absence of nails or claws. In ordinary mammals the digits never possess more than three supporting bones (*phalanges*), but the second and third fingers of a Whale may have a considerable number of such elements (fig. 645), and this increases the flexibility of the flippers. Hind-limbs are practically absent, as in Sea-Cows, but are represented by small internal vestiges. The thick smooth skin is devoid of fur or hair, though in very young specimens there may be a few bristles in the neighbourhood of the mouth. What is commercially known as "blubber" is a thick layer of fat under the skin, which, as in other similar cases, reduces the specific gravity of the body, and also keeps its owner warm.

Swimming is effected by the horizontal tail, which may be compared to a screw-propeller in its mode of action, for though no doubt there is a good deal of direct up-and-down movement, the hinder part of the body is sufficiently flexible to allow of more or less lateral strokes. This flexibility is partly due to the fact that, as in a Sea-Cow (see p. 82), the loss of hind-limbs has also obviated the necessity for a fused region in the backbone (*sacrum*) for the support of such extremities.

Cetaceans are so thoroughly adapted to an aquatic life that they soon die if stranded on the shore. They are able to traverse immense tracts of sea in a short time, and are incomparable swimmers and divers. Regarding the rapid movements of the

Killer-Whale (*Orca gladiator*), one of the toothed forms, Vogt (in *Mammalia*) says:—"The killer-whales swim in a line, one behind the other, with a speed that really makes one dizzy to look at them. I have often seen them on the coasts of Norway; they came only in heavy storms to sport round our ship." The same author makes the following remarks on the Rorqual or Fin-back Whale (*Balænoptera boöps*), a species in which teeth are replaced by whalebone:—"It is the longest, most slender, and most agile of all whalebone whales. . . . In the course of our voyage along the Norwegian coast we were accompanied for several days in the great Altenfjord by a rorqual of about the length of a two-master, which approached so near us that we could fire a bullet into its back, which appeared scarcely to tickle it. Without any apparent exertion this monstrous animal could traverse the waters with a rapidity which rendered it difficult for the gulls that swarmed around to follow it. On one occasion, when in the latitude of the Lofot Isles, we repeatedly heard thundering noises at a distance, as if proceeding from heavy artillery. When we approached we saw a large rorqual, which jumped out of the water, then plunged its head underneath the waves, turned itself vertically downwards, made two or three rapid vibrations with its enormous tail, which we guessed to be at least 20 feet in breadth, and then brought it down with a mighty stroke on the surface, producing a noise which resounded far and wide. It continued this exercise for hours together."

We know that the Cetacea are a very ancient group, but it is impossible to say much about their affinities with land mammals, for the oldest fossil remains with which we are so far acquainted are essentially whale-like, and furnish no certain clue as to their descent. By some the Hoofed Mammals (*Ungulata*) are regarded as their nearest allies, while others think their closest relatives are to be found in the Flesh-eating Mammals (*Carnivora*). But they have no close affinities with either Seals or Sea-Cows, and it is at least quite certain that they have not descended from the large marine reptiles which largely ruled the seas before the rise of the Mammalia.

Whether these creatures were first evolved as marine or as freshwater forms is another moot point. The late Professor Flower was inclined to take the latter view, on the ground that the freshwater dolphins of the Ganges and Amazons depart less

than other Cetaceans from the plan of structure found among land mammals. The other view is, however, more generally held, these freshwater species being looked upon as types which have abandoned a marine life as the result of competition with better equipped forms, and it is certainly true that rivers and lakes have served in the past as havens of refuge for hard-pressed animals belonging to quite a number of different groups. Like many other problems, this can only be settled by geological evidence, which may perhaps be forthcoming when our knowledge of extinct types is greater than it is at present.

CHAPTER XLV

MUSCULAR LOCOMOTION—CREEPING ANIMALS

CREEPING

Having now dealt with the various ways in which swimming is effected in different animals, we pass to the means by which progression on a firm surface is brought about; in other words, to those forms of locomotion which are popularly termed Creeping, Walking, Running, Climbing, and so forth. It is by no means easy to distinguish clearly between creeping and some of the other kinds of movement, and as it is impossible to draw sharp boundary lines between them, it is perhaps best to be content with distinctions of somewhat artificial kind. Creeping, then, will be taken to mean progression along a firm surface in a continuous sort of way, in the absence of well-marked jointed limbs, such as are to be found in a lobster or insect, or in ordinary backboned animals which live on land. We shall therefore be mainly concerned here with the lower groups of animals, and it will be convenient to use the word "creeping" whether the surface along which movement takes place be horizontal or inclined. But it may be as well to state that a good deal of this kind of movement might just as well be called "climbing", if by this we mean a sort of pulling of the body along as opposed to pushing it forward, the front end of the animal being first fixed by some means or another, and the rest of the body afterwards drawn up to it. But the ordinary idea of climbing also means movement along an *inclined* surface, and this involves us in a further difficulty, as may be realized by considering the case of a leech (fig. 659). This has a sucker at either end of the body, to which we may apply the names of front-sucker and hind-sucker. With the aid of these the creature can move along a firm surface, the means adopted being precisely the same

whether that surface be horizontal or inclined. Supposing the hind-sucker fixed, the body is stretched out in the desired direction, the front-sucker is then attached and the hind one loosened, after which the body is drawn forwards, and the same process is repeated indefinitely. Now, so far as the kind of movement is concerned, this certainly answers to the usual idea of climbing, but it is not usual to speak of climbing along a horizontal surface. To avoid continual hair-splitting, and mention of the same animal under two or more headings, the kind of movement described will here be called creeping, whether the surface be inclined or not, in the case of animals devoid of jointed limbs.

CREEPING ANIMALCULES (PROTOZOA)

Amœboid and ciliary movement as means of creeping have already been discussed (pp. 2 and 5), but certain other animalcules, which move about in a different fashion, deserve a brief

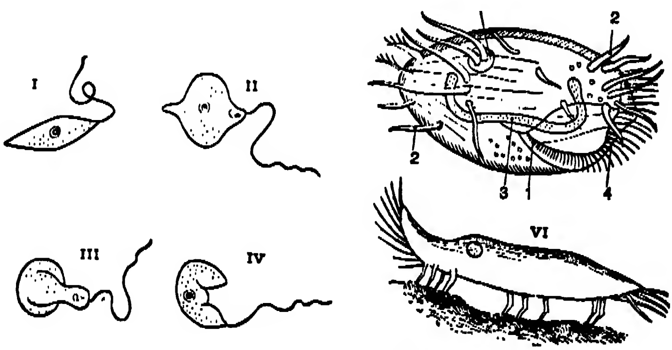


Fig. 649.—Creeping Animalcules (greatly enlarged)

I-IV, Stages in creeping movement of Euglena; V, Euplotes (under side); 1, mouth; 2, locomotor bristles; 3, nucleus; 4, cilia of mouth-groove; 5, pulsating vacuole; VI, Oxytricha creeping, as seen from the side.

notice here, though they are not, strictly speaking, illustrations of "muscular" locomotion.

One of these forms is the little worm-like creature Euglena (see vol. i, p. 494), which can wriggle along by altering the shape of its body in a fashion (fig. 649) which is so characteristic that it is technically known as "euglenoid" movement. The motive power is here afforded by the outer part of the animalcule's body, which is somewhat denser than the interior, and is specially contractile, *i.e.* is capable of shortening in one direction

with corresponding broadening in other directions. As all parts of this layer do not necessarily contract at the same time, or even in the same direction, alterations of shape of the most varied kind can be brought about. And though there is a membrane covering over the contractile layer, it is extremely elastic, and therefore permits of such alterations.

Another kind of creeping is exemplified by the members of one subdivision of those Infusorians in which the body is more or less clothed as it were with cilia (Ciliata). The creatures in question (fig. 649) are of flattened shape, showing a well-marked distinction between upper and lower surfaces, this being a peculiarity related to the creeping habit. The upper side is altogether devoid of ordinary cilia, while the under surface is provided not only with these, but also with a number of bristle-like structures which can almost be called "legs", for they act as such. They have probably arisen by the fusion of groups of cilia, somewhat in the same way that rowing-plates have been formed in the Comb-Jellies (see p. 20). They are connected with a specially contractile external layer of the body, something like that of Euglena, but in this case partly made up of thread-shaped structures which are comparable in mode of action to muscle-fibres (see p. 8). It is some of these fibres which move the "legs" in such a way as to bring about creeping, and, as we shall see later, an interesting comparison may be made with certain sea-urchins, which move about by means of the spines on their under surface, thus progressing as it were on stilts.

CREEPING JELLY-FISHES OR MEDUSÆ (HYDROZOA)

An ordinary Jelly-Fish or Medusa is shaped in accordance with its swimming habit, as already described (see p. 18), but some such forms are also able to creep in a curious and characteristic manner. It may be well to recall the comparison, as to shape, elsewhere made between a jelly-fish and an umbrella with a straight handle. The expanded part of the former serves as a swimming organ, and the mouth is placed at the end of the "handle". Round the edge of the expansion are a number of tentacles, varying in kind and number according to species, and these we may liken to the fringe round the edge of an ornamental parasol. In such a creeping form as the one represented

in fig. 650 (*Pectanthis asteroides*), many of these tentacles end in adhesive discs that can attach themselves to the underlying surface, thus enabling creeping movements to be executed. For some of the tentacles are stretched out in the direction of movement, and attached by their suckers, this being followed by a shortening or contraction which must clearly pull or drag the

Fig. 650.—Creeping Jelly-Fishes (*Pectanthis asteroides*)

animal forwards. And it appears to be a matter of indifference whether the handle-side is below or above. In the latter case, of course, the umbrella is partly turned inside out, a process to which its flabby nature offers no particular obstacle (see individual on left in foreground of fig. 650).

CREEPING HEDGEHOG-SKINNED ANIMALS (ECHINODERMATA)

Ordinary Star-Fishes (Asteroids), Sea-Urchins (Echinoids), and Sea-Cucumbers (Holothurians), when adult, are essentially creeping forms, though their movements are not all effected in precisely the same way.

STAR-FISHES (*Asteroidea*).—Ordinary Star-Fishes, as contrasted with Brittle-Stars, creep by means of very numerous *tube-feet*, lodged in five grooves which radiate from the mouth, on the under side of the body. In most cases these end in suckers, as for instance in the Common Star-Fish (*Uraster rubens*), and are used much in the same way as the tentacles of the creeping jelly-fishes already described. This will be obvious on examination of fig. 651, which shows one of these animals creeping up the glass side of an aquarium. Some of the tube-feet

have stretched up and fixed their tips to the glass, and in the next stage the body will be dragged up a little by their shortening. These creeping organs form part of the *water-vascular system*, which is highly characteristic of Echinoderms generally, though it is not always used in creeping, as in this case (see vol. ii, p. 414). The nature and arrangements of its parts is briefly as follows (fig. 652):—On the upper side of the body, in the interval between two of the arms, a small round plate (madreporite) can be easily seen, the surface of which is marked by winding ridges. In the grooves between these there are a large number of small holes, through which sea-water enters by ciliary action into a tube (the stone canal) that runs down and opens into a hollow ring surrounding the gullet. From this ring a long tube (radial vessel) runs along each arm, lodged in the groove on its under side, and branching into a double series of tube-feet. At the base of each foot is a little swelling or bladder (ampulla) situated within the skeleton

Fig. 651.—Common Star-Fish (*Uraster rubens*) creeping up the glass side of an aquarium

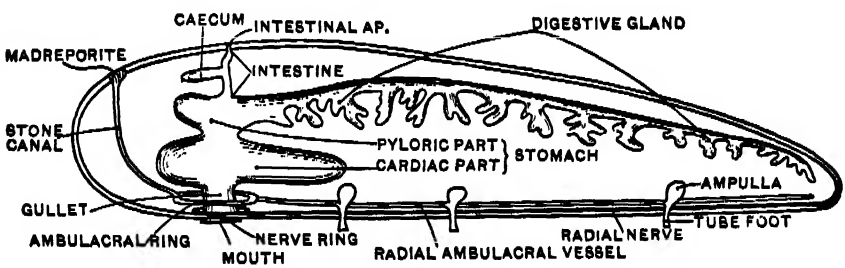


Fig. 652.—Vertical Section through disc and one arm of Common Star-Fish (*Uraster rubens*), diagrammatic

of the arm. By cutting open an arm from the upper side, and clearing away the branches of the stomach therein contained, these ampullæ will be easily seen. Their use is obvious, for muscle-fibres are contained in their walls, by the contraction of which water is squeezed into the corresponding tube-feet, just as a heart squeezes blood into arteries, the result being that these structures are lengthened and protruded. Valves are present which prevent the water from passing into the radial vessels instead of

into the feet. The opposite process of shortening of the tube-feet is effected by contraction of muscle-fibres which run in their walls in the direction of their length, the ampullæ at the same time relaxing and receiving a fresh supply of water from the radial vessel. In many Star-Fishes, though not in the common sort here described, also in Sea-Urchins and Sea-Cucumbers, a number of stalked sacs (Polian vesicles) are attached to the water-vascular ring, and apparently serve as reservoirs of fluid, which by their contraction is forced into the radial vessels. It seems at first sight somewhat mysterious that the water-vascular system should permanently communicate with the exterior, from which water appears to constantly if slowly enter it. Regarding this point Shipley and MacBride (in *An Elementary Text-book of Zoology*) speak as follows, where they describe the valves already mentioned:—"These valves swing open into the tube-foot when the pressure in the radial tube is greater than the pressure in the tube-foot, but when the pressure in the latter is the higher, they close, so that under no circumstances can water escape from the tube-foot into the radial canal. So it appears that there is an arrangement which allows fluid to pass into the tube-foot but prevents its return, and this implies that under ordinary circumstances there must be a loss of fluid. We must, in fact, suppose that when the tube-foot is driven out by the contraction of the ampulla, the contained fluid slowly transudes through its thin walls, and the loss is supplied from the radial canal." Hence the constant inflow of water from the exterior to make good this waste.

There are some Star-Fishes in which the tube-feet have pointed ends, quite devoid of suckers, and this, of course, alters the character of their creeping movements. Romanes says of them (in *Jelly-Fish, Star-Fish, and Sea-Urchins*):—"These star-fish, therefore, assist themselves in locomotion by the muscular movement of their rays, while they use their suckerless feet to run along the ground somewhat after the manner of centipedes".

SEA-URCHINS (*Echinoidea*).—In a regular spheroidal form, such as the Edible Urchin (*Echinus esculentus*), the water-vascular system is constructed on much the same type as in a star-fish, except that the radial vessels run within the firm, continuous test through which the tube-feet protrude (see vol. i, p. 456). Speaking of the urchin as if it were a globe, we may say that

the tube-feet are arranged in five meridional bands, equivalent to the five grooves on the under side of a star-fish; and if a broken test be held up to the light, a series of pairs of little holes will be seen on either side of each such band, every pair corresponding to a tube-foot. A Sea-Urchin is also covered with numerous spines, which are attached by ball-and-socket joints to knobs on the test. These spines can be moved in different directions by muscle-fibres which are attached to their bases. Creeping is effected much as in a star-fish, by the agency of the tube-feet, which have suckers at their ends. Some of them are protruded in the direction of movement, hold on with their suckers, and then shorten so as to drag the body onwards. But a compact creature like an urchin is more difficult to pull along than a flattened animal like a star-fish, and creeping is aided by the spines, as shown diagrammatically in fig. 653. The tips of certain spines are pressed against the underlying surface, constituting a series of firm points over which the body is swung as it were when the pulling tube-feet shorten. In this process the utility of the ball-and-socket joints is obvious. The arrangement is so effective that by its means even vertical surfaces can be ascended, though by no means so readily as in the case of star-fishes.

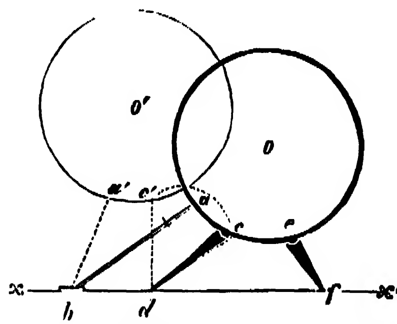


Fig. 653.—Diagram of Creeping Sea-Urchin. Only one tube-foot and two spines are represented

The tube-foot, *ab*, is extended, fixed to underlying surface *xx'*, and shortened, bringing it to position *a'b*. The body, *o*, is thus pulled forwards to *o'*, the tip of the spine, *cd*, serving as a fixed point, and its base travelling to *c'*; *ef*, a second spine supporting the body.

The oldest known extinct Sea-Urchins are spheroidal, as in the least specialized existing forms, and some of them are even melon-shaped. This is clearly an obstacle to rapid creeping, and it is not therefore surprising to find that the most specialized urchins have acquired a more or less flattened shape, which has no doubt been acquired in relation to the creeping mode of life. Such species have also become "irregular", *i.e.* they have acquired a marked two-sided or bilateral symmetry as opposed to the radial symmetry of the ordinary spheroidal type. In such cases only the tube-feet on the flattened under side are used for creeping, while those on the upper surface serve as breathing organs (see vol. ii,

p. 415). The bilateral symmetry has no doubt been evolved in relation to creeping with the same region of the body constantly kept in front. Indeed, it is only among the simpler forms of life that radial symmetry is to be found, especially among fixed forms such as corals and the like, where the influences to which the animal is exposed are similar in all directions, except above and below. For reasons chiefly connected with feeding, the

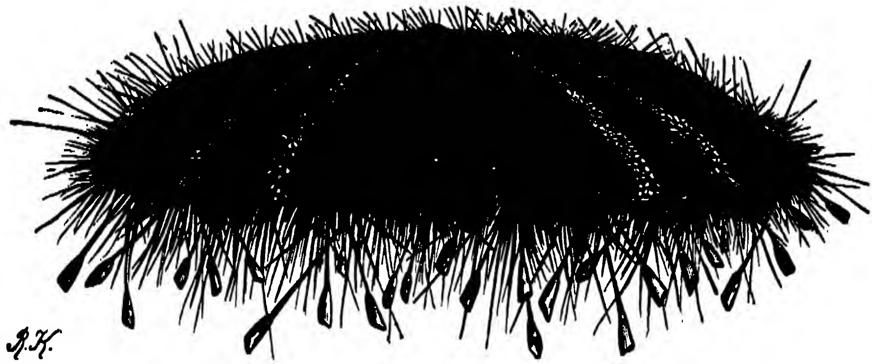


Fig. 654.—A Stilt Urchin (*Phormosoma luculenta*)

radial symmetry is by no means perfect in all these simple kinds of animal (see vol. ii, p. 417), and it is probable that the immediate ancestors of Star-Fishes, Sea-Urchins, and the like were bilaterally symmetrical (see vol. i, p. 450), so that in this group the radial symmetry exhibited is *secondary*, *i.e.* has been acquired during the history of the group and is not an inheritance from earlier types.

Speaking broadly, however, there can be no doubt that radial symmetry is a very primitive sort of regularity, and we are justified in thinking that bilateral symmetry as exemplified by Worms, Centipedes, Insects, Vertebrates, &c., was originally evolved in adaptation to locomotion with the same part of the body always leading, instead of any part, on the same principle, in short, as that employed to explain in the last paragraph the two-sidedness of an irregular urchin. The matter has previously been dealt with to some extent in vol. i, p. 21.

We have seen that the spines of a Sea-Urchin play an important part in creeping, and it now remains to be stated that there are certain flattened deep-sea forms, which creep by means of spines only. Such a "Stilt Urchin" (*Phormosoma luculenta*) is represented in fig. 654, from which it will be seen that the

under surface bears a number of long spines with broadened ends. Tube-feet ending in suckers are most useful in cases where there are rocks or other firm bodies for them to lay hold of, but not so well adapted for crawling on the surface of the soft muds and oozes which cover the sea-floor where the water is very deep. And it is obvious that broad-ended spines here answer the purpose much better, for rigidity is desirable, and ordinary spines would be less effective, as their sharp tips would penetrate too deeply into the yielding underlying surface. It is also interesting to notice that the plates making up the test of Phormosoma, and some of the other urchins found in the deep sea, are so united together as to confer a certain amount of flexibility, while the tests of other forms are perfectly rigid.

Sea-Cucumbers (*Holothurians*).—The members of this group which live in shallow water are cylindrical in shape, with the tentacle-surrounded mouth at one end, and the opening of the intestine at the other (see vol. i, p. 462). In comparing such a creature with a regular spheroidal sea-urchin, we must suppose the latter drawn out into a cylinder in the direction of the vertical axis which passes from the upper pole of the body to the lower. In most respects the water-vascular system is constructed on the plan already described for a star-fish, there being a ring round the gullet from which five longitudinal radial vessels pass backwards, bearing tube-feet, which project externally, and are the chief agents in creeping. Variously-shaped calcareous plates are scattered through the skin, but these are not connected together into a firm test as in a sea-urchin, so that the body is perfectly flexible. Layers of muscle in the body-wall of a practically rigid sea-urchin would be of no use for locomotion, but here the case is different, and we accordingly find them well developed. Under the leathery skin is a continuous coat of muscle-fibres which run transversely, and inside this are five double bands of longitudinal fibres. Such an arrangement is common in worm-like lower forms, and is obviously able to help in creeping, for the body can be stretched out and narrowed by contraction of the circular layer, while the longitudinal bands when they contract of course make the body shorter and broader.

There is a remarkable peculiarity about the stone-canal of these ordinary kinds of Sea-Cucumber, for the madreporite in which it ends does not project at the exterior, but hangs down

into the large cavity of the body in which the digestive and other organs are contained. And, as a result, the fluid lost by the water-vascular system by diffusion to the exterior through the tube-feet must be made good from the liquid contents of the body-cavity, and there must therefore be some means of renewing these contents in their turn. This means is supplied by the branching hollow structures (respiratory trees) which open into the last part of the intestine, and are constantly taking up sea-water from the exterior and expelling it again in the performance of their duties as breathing organs (see vol. ii, p. 414). It appears that the walls of these trees are pierced by innumerable minute holes through which fluid can pass into the surrounding body-cavity, a constant supply of liquid in which is thus kept up.

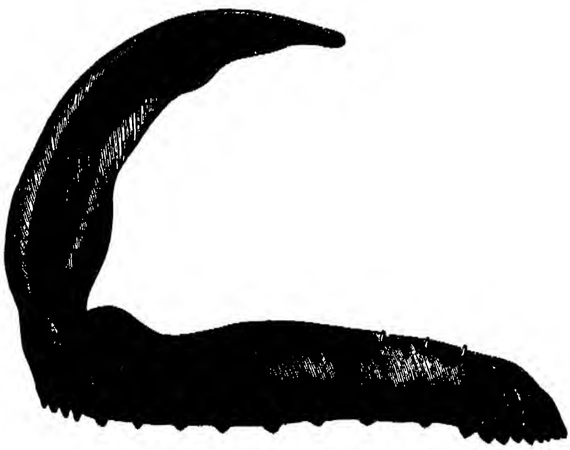


Fig. 655.—A Sea-Cucumber (*Psychropotes*) from the deep sea
The front end is placed to the right, and the back end bears a large tail-like projection on its upper side.

The members of one remarkable family of Sea-Cucumbers (*Elasipoda*) are peculiar to the deep sea, where they creep about on the mud or ooze, and swallow this for the sake of its nutritive contents. These forms vary greatly as to their shape, which is often extraordinary (fig. 655), but they nearly all agree in being markedly two-sided, and in the fact that one side of the body is modified into a flattened creeping sole, along which run three of the five longitudinal bands of tube-feet. The other two bands, which are not on the under side of the body, have lost their locomotor function and have become modified in shape, reminding us of the specializations which take place in the flattened forms of Sea-Urchin (p. 93). It is usual for the stone-canal of these deep-sea species to open directly to the exterior, so that the water-vascular system can renew its fluid as in a star-fish or sea-urchin. And in connection with this it

is rather interesting to find that respiratory trees are either absent altogether or of very small size. One reason for this may perhaps be that as the stone-canal opens directly to the exterior it does not draw upon the fluid in the body-cavity, so that replenishment of this through the pores of such trees is not necessary as in the ordinary Sea-Cucumbers.

Another very interesting case is that of the Footless Sea-Cucumbers (*Synapta*, &c., fig. 656), worm-shaped creatures in which radial canals and tube-feet are entirely absent. Creeping is effected by the tentacles, and by the muscular layers of the body-wall. And in this case too respiratory trees are entirely absent. They are certainly not required to keep up the supply of fluid in the water-vascular system. The calcareous plates in the skins of these footless forms are of characteristic shape, resembling wheels, anchors (fig. 656), &c., and they will be found in most general collections of microscopic slides, in which they are included on account of their attractive appearance. The anchors project externally, and are of use in crawling and burrowing. For supposing the front end of the body stretched out by contraction of the layer of circular muscle, these hooked plates afford a hold on the surrounding mud, which prevents backward slipping while the body is being dragged forwards by the active shortening of the longitudinal muscle-bands.

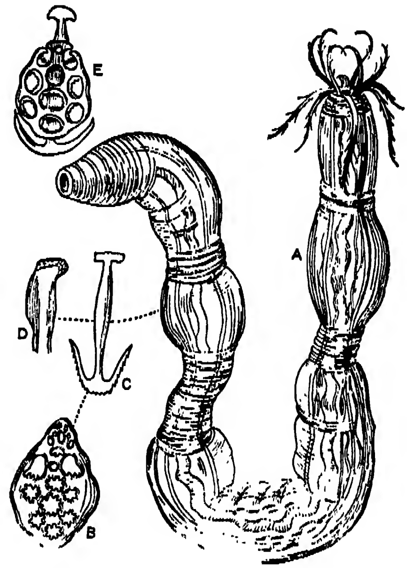


Fig. 656.—A, A Footless Sea-Cucumber (*Synapta*), reduced. B–E, Calcareous plates from skin of a Synapta, enlarged

CREEPING ANNELIDS (Annelida)

We are nere concerned with Bristle-Worms (*Chætopoda*) and Leeches (*Discophora*), the members of which groups crawl by somewhat different methods.

Bristle-Worms (*Chætopoda*).—Examination of one of the wandering or errant Annelids, such as the Sea-Centipede (*Nereis*,

fig. 657), will show that its much-elongated body is made up of a large number of successive rings or segments, each of which bears a pair of blunt foot-stumps (parapods) in which a considerable number of stiff bristles are imbedded. The animal can crawl with considerable rapidity, its body undulating from side to side, and a sort of wave-like movement passing from one end of the body to the other, with successive movement of the foot-stumps. The appearance presented strongly suggests a centipede, and the popular name has no doubt been given on this account.

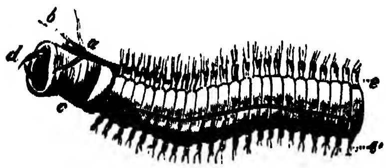


Fig. 657.--Front End of a Sea-Centipede (*Nereis*), seen from below. *a*, Head, with feelers, *b*; *c*, protruded pharynx, with jaws, *d*; *e e′*, bristle-bearing foot-stumps (parapods)

A cross-section through the body (fig. 658) shows that the body-wall contains muscular layers arranged on the same plan as in a sea-cucumber, *i.e.* an external circular coat, and within this longitudinal bands, of which in this case there are four, two above and two below. A foot-stump will be seen to be made up of an upper and a lower projection, each containing a long central bristle, of which only the tip projects, and which acts as a sort of stiffening, and numerous slender ones with curved ends.

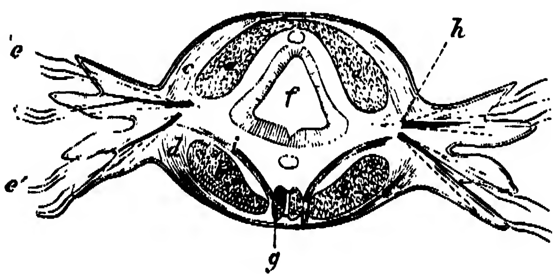


Fig. 658.- Enlarged cross-section through a Sea-Centipede (*Nereis*)

f, Intestine, above and below which are oval marks representing blood-vessels; *g*, nerve-cord; *a a′*, *b b′*, longitudinal muscle-bands, and outside this is circular muscle-layer, of which parts, *c d*, help to move foot-stumps; *i*, oblique muscle-bands connected with foot-stumps; *e e′*, small bristles; *h*, central bristle, special muscle strands connected with which are indicated by dotted lines.

Two effective ways of creeping are here practicable. The first is much after the fashion of that practised by a footless Sea-Cucumber (see p. 97). By contraction of the circular coat of muscle in the body-wall the front part of the animal can be stretched forwards, fixed by the agency of the bristles, and then the hinder part dragged up by shortening of the longitudinal muscle-bands. But the foot-stumps can also be employed as legs, for they can be moved in various directions by the little muscle-bands that are attached to them, so as to push back on the underlying surface, and give the body a forward shove. Though this

kind of locomotion is here described under the head of crawling, it might with equal or even greater propriety be considered as a *primitive sort of walking, and it is, in fact, the precise method of* progression from which has been derived the walking of jointed-legged animals (Arthropods), such as Centipedes, Spiders, Insects, Lobsters, and similar forms of life.

It may be here remarked that there are a few very simple segmented Worms (Archiannelids, see vol. i, p. 431), which are entirely devoid of foot-stumps and bristles. One of these (*Poly gordius*) is a much-elongated very slender creature, which creeps by means of the muscle-layers in the body-wall, in the manner already more than once described.

LEECHES (*Discophora*).—These Annelids never possess foot-stumps, and are almost always quite devoid of bristles. There is a sucker at either end of the body, by the alternate attachment

Fig. 659.—Stages in the Creeping of a Leech (diagrammatic). Direction of movement indicated by arrows

of which the animal is able to creep by "looping" itself along in the manner already described (p. 87). It only remains to add here that the stretching forward of the front part of the body, and the dragging up to the fixed front sucker, are both results of contraction in the muscular layers of the body-wall.

CREEPING MOSS-POLYPES (POLYZOA)

We have already seen that some colonial animals, *e.g.* the Compound Jelly-Fishes, are able to swim; the group now under consideration presents certain cases of creeping colonies, though this is the exception, and not the rule. In an ordinary Moss-polype the body is invested by a firm horny layer, which serves as a protection, and is well suited to a fixed habit of life. But in the creeping forms so far observed, all of which, by the way, inhabit fresh water, the individual members of the colony are imbedded in the upper surface of a gelatinous mass, into which they can be withdrawn by special muscular bands (retractor muscles), or from which they can protrude while feeding and breathing. The under side of the colony constitutes a creeping surface. Two such

species are native to Britain. One is the beautiful little translucent Lophopus, figured in vol. i, p. 437. The other is Cristatella (fig. 660), a flattened oval form, with a very definite sole-like creeping surface. The exact nature of the movement is not definitely known, but the observations so far made render it likely that muscle-cells belonging to the "sole" play some part in locomotion, which is probably also aided by the muscle-bands that retract the individual polypes, for these bands are attached below to the under side of the colony. Harmer (in *The Cambridge Natural History*) gives details concerning observations on the rate of movement of both Lophopus and Cristatella. A small colony of the former was observed to move from ¼ to ⅓ inch per day, *i.e.* its own length or a little more. A specimen of Cristatella rather more than ¼ inch long moved at an average rate of about ½ inch per day during the three days over which the observations extended. One very large creeping Moss-Polype (*Pectinatella*) has been found in Germany, Japan, and America. A Japanese species (*P. gelatinosa*) may attain the length of 6 feet, with a thickness of from 4 to 8 inches.

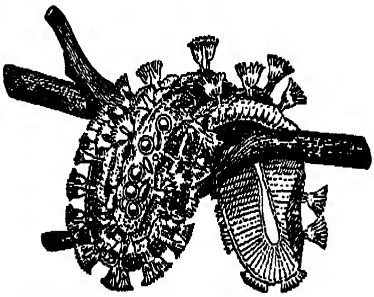


Fig. 660.—A Creeping Moss-Polype (*Cristatella*)

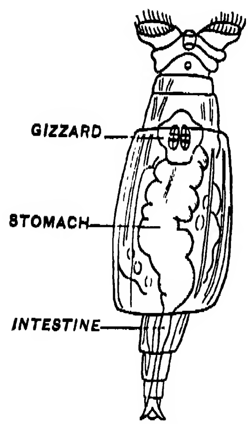


Fig. 661.—Rose-coloured Rotifer (*Philodina roseola*), enlarged. Below is seen the "foot", ending in pincers.

CREEPING WHEEL-ANIMALCULES (ROTIFERA)

Some of these minute creatures, as, for instance, the Rose-coloured Rotifer (*Philodina roseola*, fig. 661), are able to creep by looping themselves along after the fashion of a leech. The hinder end of the body tapers into a sort of jointed tail (the "foot") provided with a pair of pincers, and capable of executing telescopic movements by the agency of muscle-fibres in the body-wall, some of these running longitudinally and others transversely. During creeping the wheel-organ is pulled in, and the front end of the body is employed after the same fashion as the anterior

sucker of a Leech (see p. 87), while the pincer-bearing tail answers the same purpose as a posterior sucker.

CREEPING JOINTED-LIMBED ANIMALS (ARTHROPODA)

The two most interesting cases here meriting notice are afforded by the primitive form Peripatus, and the "Looper" Caterpillars, which are the larval stages in the life-history of certain moths.

PERIPATUS (see vol. i, p. 398) is a caterpillar-like creature native to many of the warmer parts of both Old and New Worlds, and presents so many peculiarities of structure that it is placed in a class of its own (Prototracheata). Although it is an undoubted Arthropod, resembling Millipedes and Centipedes in many respects, it differs from these and agrees with the Bristle-Worms in several particulars, especially as regards the organs by which locomotion is effected. As in such a worm the body-wall underneath the skin is made up of muscle, of which there is an external circular and an internal longitudinal layer (compare fig. 658). When examined under the microscope the fibres making up these layers are found to be unstriated, and this is a further point of agreement with a bristle-worm, and difference from an ordinary Arthropod, in which the fibres are well-striated (see p. 12), a feature which is always associated with vigorous powers of contraction. The limbs of such typical Arthropods as Millipedes, Insects, and Scorpions are solid, and sharply divided into a number of joints capable of being more or less bent upon one another. *It is, indeed, this feature which has earned for the group both its popular ("jointed-limbed" animals) and scientific names* (Arthropoda, from Gr. *arthros*, a joint; *pous podos*, a foot). Peripatus is possessed of many pairs of legs, all much alike, and the exact number varying according to the particular species. Each such limb is a conical hollow structure bearing a pair of sharp claws at its tip, and exhibiting only in an imperfect and incipient manner the characteristic jointing of the Arthropod group. Indeed, it strikingly resembles the hollow foot-stump of a Bristle-Worm (see p. 98), except that it is not divided into upper and lower portions, and we are almost tempted to compare its claws with the bristles of a foot-stump. In both a Peripatus leg and a Bristle-Worm foot-stump movement is brought about by muscle-bands which are connected with the wall of the body.

By successive movement of its legs Peripatus is able to crawl slowly along under the bark of decaying tree-stumps, or in the other dark places where it is found. Regarding this Sedgwick remarks (in *The Cambridge Natural History*):—"They avoid light, and are therefore rarely seen. They move with great deliberation, picking their course by means of their antennæ and eyes. It is by the former that they acquire a knowledge of the ground over which they are travelling, and by the latter that they avoid the light. The antennæ are extraordinarily sensitive, and so delicate, indeed, that they seem to be able to perceive the nature of objects without actual contact."

Looper Caterpillars.—The larvæ of a large and cosmopolitan family of Moths (*Geometridæ*), of which some 270 species are native to Britain, are the very interesting "Stick" Caterpillars, elsewhere described in regard to protective devices (see vol. ii, p. 297). They are also known as Loopers or Geometers, on account of their curious mode of progression, which is effected on much the same principle already described for leeches (p. 87). Near the front end of the long slender body are the three pairs of small jointed legs which correspond to those of the adult moth, and near the posterior end are two pair of unjointed sucker-tipped pro-legs. The entire absence of limbs from the rest of the body necessitates a looping kind of locomotion, which has suggested the popular names given to these caterpillars. By means of the pro-legs a firm hold is obtained on the underlying surface, the body is then stretched forwards and the three pairs of jointed legs fixed to some convenient point. The pro-legs are now detached, and the hinder part of the body drawn up to the front and thrown into a loop (fig. 662). By a repetition of

Fig. 662.—Looper or Stick Caterpillars of Brimstone Moth (*Rumia cratægata*), in characteristic attitudes

this procedure the caterpillar is able to creep with fair speed.

An ordinary caterpillar possesses a much larger number of pro-legs, by means of which and the ordinary jointed legs it is able to creep after the fashion of Peripatus. A case like this illustrates in a curious way the difficulty of drawing sharp boundary-lines between different modes of locomotion. It will be remembered that, for the sake of convenience, we have limited the use of the word "creeping" to animals devoid of jointed limbs, reserving for such forms the terms "walking" and "running". But it will not do to apply these terms too strictly in this particular case, as it would necessitate describing the locomotion of an ordinary caterpillar as partly creeping, partly walking: creeping in so far as brought about by the unjointed pro-legs, and walking as to the part of it effected by the three pairs of jointed legs. Similar anomalies would result in all probability if such words as "creeping" and "walking" were otherwise defined, and the matter may serve as an illustration of the difficulty of constructing definitions beyond cavil when dealing with the structure and actions of animals.

The caterpillars of some of the Owlet Moths (*Noctuidæ*) are intermediate in character between the Loopers and ordinary moth larvæ, as to the pro-legs, of which they possess a larger number than the former and a smaller number than the latter. As a result of this they "loop" to some extent while creeping, and on this account are known as Half-Loopers.

CREEPING MOLLUSCS (MOLLUSCA)

The characteristic locomotor organ of Molluscs is a muscular outgrowth from the under side of the body. This is known as the *foot*, and it varies greatly in shape and structure according to the uses to which it is put. It is sometimes a swimming organ (see p. 35), or it may be adapted to creeping, leaping, or burrowing. The sucker-bearing tentacles which surround the mouth of a Cuttle-Fish or Octopus (see p. 31) are believed by most zoologists to represent the front part of the foot, that has surrounded and fused with the head to constitute an arrangement for capturing prey, which can, however, also be used for creeping. And, as we have seen, this capture apparatus has in some instances

become modified into a swimming-bell (see p. 33). In one of the most primitive of existing Molluscs, the Mail-Shell (*Chiton*, vol. i, p. 340), the foot is a broad sole-like expansion by which creeping is effected, and it is probable that this organ was either evolved in the first instance as a means of creeping, or else very soon acquired that function.

The Mail-Shells belong to the most simply organized sub-division of the Mollusca (class *Amphineura*), but creeping as a means of progression is also exemplified by animals which belong to three other classes, *i.e.* Snails and Slugs (*Gastropoda*), Cuttle-Fishes, &c. (*Cephalopoda*), and Bivalves (*Lamellibranchia*).

It will save repetition to remark here that the foot of a Mollusc is capable of being more or less altered as to shape and size in the same individual under different circumstances. This is partly due to contractions of the muscle so abundantly present, but is also dependent upon the amount of blood contained for the time being. In fact, blood can be pumped into the foot so as to make it larger, or withdrawn so as to make it smaller.

CREEPING SNAILS AND SLUGS (*Gastropoda*).—It is convenient to begin with this class, because most of its members creep, either under water or on the land. Many species, such as those which live between tide-marks, move about in this way with equal ease both when submerged and when left high and dry.

The creeping mode of progression can be easily observed in a Garden-Snail (*Helix aspersa*) placed upon a piece of glass so that the under surface of the foot can be seen through it, and equally favourable objects of investigation are a Limpet (*Patella vulgata*) moving along the glass front of a salt-water aquarium, or a Pond-Snail (*Limnæa stagnalis*) progressing in similar fashion on the surface of a bell-jar filled with fresh water. In any one of these or similar cases the movement may be described as a sort of slow gliding, friction being reduced by a kind of slime which exudes from special glands as well as from the skin of the foot. Probably everyone has noticed the gleaming track which marks the progress of a garden-snail over the surface of a wall or cabbage-leaf. Closer examination will show that a series of undulations indicated by dark transverse bands pass along the foot from back to front, and are clearly related to the creeping, for they cease when the animal comes to a stand-still. These waves are undoubtedly the expression of muscular contractions, but they

do not, as might be at first sight supposed, prove the presence of a series of temporary wrinkles. The foot is closely applied all the time to the underlying surface, and the wave-like appearances are due to changes which take place within its substance.

The exact way in which a snail slides along in its own slime is by no means certain, but perhaps the most plausible explanation is one given by Simroth, though it is by no means free from objection. This observer finds that the foot of the snail is made up of a complicated network of muscle-fibres running in various directions, and he considers that creeping is mainly effected by the longitudinal fibres, which, according to him, do not shorten and thicken when they contract, as happens in ordinary muscle-fibres (see p. 10), but become longer and larger. Suppose this to take place in the front end of the foot, the result will be a slight forward advance of that region. And when the same fibres cease to contract they become shorter, and exert a pulling action that tends to drag up the foot to the front edge, which has gained ground. A succession of such contractions and relaxations, travelling along the longitudinal muscles of the foot, as indicated by the wave-like appearances, are supposed to bring about a gradual onward movement. However produced, the rate of progress is not very impressive, for it has been calculated that a garden-snail of average size and activity requires sixteen days fourteen hours to creep a mile. If we take two inches as a liberal estimate of the length of the extended foot, this calculation, otherwise expressed, means that a snail travels about 160 inches per hour, that is to say, eighty times its own length. A horse at the walk goes four miles in an hour, and its length may be taken at eight feet. It thus traverses 2640 times its own length per hour. We may say, therefore, that the horse, at its slowest pace, is thirty-three times as swift as a garden-snail. Nor can the latter adopt any swifter mode of progression, for as Scharff says: "Although this mode of locomotion may seem very pleasant, being at any rate quite unique among animals, the snail's lot is not a happy one. When the locomotor muscles are once set a-going . . . the snail can neither increase nor slacken its pace, nor can it go backwards. In that respect it is like a watch which may be wound up and which we can stop at will, but we cannot force the wheels to change their rate of velocity. Hence when the snail is pursued by an enemy, it is unable to run away,

or rather slide away. The only possible manner to evade the enemy is to stop the motion of the foot and wind up another series of muscles by means of which the snail is enabled to retire within its shell."

It might at first sight be thought that the lubricating slime which a snail pours out would cause it to slip back, but it appears that in reality it enables the animal to adhere very closely to the underlying surface, for it can easily drag along relatively heavy weights, which further indicates that great expenditure of muscular power is necessary to produce a very tedious mode of locomotion. The relatively great size of the foot points to the same conclusion. Cooke (in *The Cambridge Natural History*) gives the following details as to experiments on the pulling powers of garden-snails carried out by Sandford:—"He found [a specimen weighing ¼ oz.] could drag vertically a weight of 2¼ ozs., or nine times its own weight. Another snail, weighing ⅓ oz., was able to drag in a horizontal direction along a smooth table twelve reels of cotton, a pair of scissors, a screw-driver, a key, and a knife, weighing in all no less than 17 ozs., or more than fifty times its own weight. This latter experiment was much the same as asking a man of 12 stone to pull a load of over 3¾ tons."

Although the creeping movements of a snail or slug are slow, and involve a relatively large expenditure of energy, there are certain advantages in this mode of progression, especially in the case of aquatic forms. The sensitive and mobile foot is able to adapt itself to very irregular surfaces, and can clasp a narrow object. A Pond-Snail, for example, can creep with ease along the stem of a water-plant, round which its foot is wrapped, and though not able to move backwards can easily change the direction of its course.

Specialized ways of Creeping among Gastropods.—In addition to the ordinary method of locomotion as already described, there are interesting species of snail-like animals which creep in a somewhat different manner. A very remarkable specialization of the kind is exemplified by one of the Land-Snails (*Cyclostoma elegans*), and by the marine Pheasant-Shells (*Phasianella*). In these creatures the foot is divided by a longitudinal furrow into right and left halves, which are advanced alternately. And it is particularly interesting to note that these are in turn lifted from the underlying surface during the forward movement, so that there is a great reduction of friction.

FRESHWATER LUNG-SNAILS (*Pulmonata*)

These Molluscs creep in a characteristic manner by means of a fleshy expansion of the under side of the body, which is known as the foot. This possesses a sole-like surface that is closely applied to a stone or water-plant, as shown in the figure. The movement is of a gliding character, but exactly how it is effected is not clearly understood. The forms here represented are: 1, Fountain-Snail (*Physa*); 2, Amber-Snail (*Succinea*); 3, 4, 5, Pond-Snails (species of *Limnæus*); 3b, spawn of Pond-Snail (*Limnæus*); 6 and 7, Trumpet-Snails (species of *Planorbis*); 6a, spawn of Trumpet-Snail (*Planorbis*); 8a and 8b, male and female River-Snails (*Paludina vivipara*). A small freshwater bivalve (*Cyclas*), with extended siphons and foot, is also shown (9).

FRESHWATER LUNG-SNAILS (PULMONATA)

There are also a number of cases where the creeping is reminiscent of the looping mode of progression observed in a Leech (see p. 87), and here the foot appears to act as a whole, alternately lengthening and shortening. There is no longer the close adhesion to an underlying surface which is so characteristic of the gliding movement of average forms, and no longer therefore a large amount of retarding friction. Such special methods of creeping are associated with the presence of structures which play the same part as the suckers of a leech, and which are more particularly necessary when these animals are traversing steeply inclined and even vertical surfaces, or it may be crawling along the under side of a rock or piece of sea-weed. Some of these arrangements are outlined in fig. 663, only the head (top of figure) and foot being represented. In all these cases the mouth-region can be used as a sucker (indicated by the dark line in the figure), which may assist in the progress of the ordinary gliding forms (A). In Notarchus (B), a relative of the Sea-Hare (see p. 35) but with a very minute shell, there is a sucker on the front of the foot. In the lung-snail Pedipes (C), which lives just above high-water mark on rocks kept damp by the sea-spray, the front part of the foot (fore-foot) is clearly marked off by a transverse groove, and is of suctorial character. When the animal crawls, this region is extended forwards and holds on to the underlying surface, after which the body is drawn onwards, much as in a leech. There is a still further specialization in the marine Wing-Snails (*Strombus*, D), which possess a narrow pointed fore-foot, ending in a sucker (*a*), and also a well-marked hind-foot, upon the upper side of which is borne a toothed horny plate (*b*), the operculum, that serves as a kind of door when the animal withdraws into its shell. The fore-foot is used as in Pedipes, while the hind-foot can be bent round and used as a lever to shove its owner forwards.

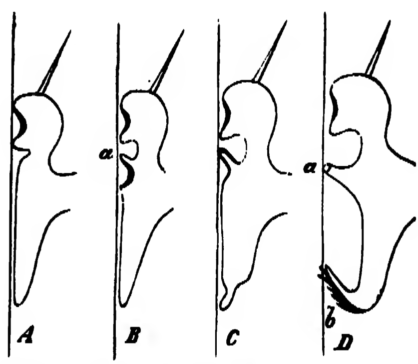


Fig. 663.—Diagram of Sea-Snails creeping up a vertical surface (only head and foot are shown)

A, Ordinary gliding type; B, Notarchus, with sucker, *a*, on front of foot; C, Pedipes, in which fore-foot (darkly outlined) is suctorial; D, Wing-Snail (*Strombus*), with sucker, *a*, and toothed operculum, *b*.

The preceding series of cases mean more or less reduction

of the area of the foot applied to the underlying surface; but arrangements of exactly opposite character are known in certain sea-snails which crawl on the surface of wet sand, into which there is a tendency to sink. In Bullia, for instance, a relative of the Dog-Whelk, the foot when in use is stretched out in all directions to a quite remarkable extent, assuming the form of a relatively thin plate.

Creeping Bivalve Molluscs (*Lamellibranchia*).—The foot of an average bivalve is specialized into a burrowing organ, as we shall have occasion to note in a subsequent section. There are, however, a few cases (*Nucula*, *Solenomya*, &c.) where this organ is possessed of a creeping sole-like under surface, which is used in much the same way as in an ordinary snail (fig. 664). In some instances an intermediate condition is found. There is good reason for believing that the remote ancestors of bivalves were creeping forms, and that in them the foot had a corresponding form. In view of this it is particularly interesting to note that most of those bivalves which at the present day are typical creepers may in other respects be regarded as the most primitive members of their class. They have probably therefore retained what must be regarded as the old method of locomotion. A limited number of more specialized bivalves, however, are able to creep. It is one of these which is depicted in fig. 664.

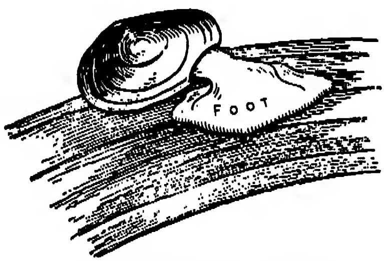


Fig. 664.—A Creeping Bivalve (*Erycina*)

Creeping Head-Footed Molluscs (*Cephalopoda*).—It has several times been pointed out in preceding sections that in this group of Molluscs the front part of the foot has grown round and intimately fused with the head, and that the development of suckers or other adhesive structures upon its surface have converted it into a very efficient organ for capturing prey. But these same structures also enable the greatly specialized fore-foot to act as a creeping organ. In the Pearly Nautilus (*Nautilus pompilius*), the most primitive member of its class, this foot consists of a number of lobes or lappets in the neighbourhood of the mouth, and these bear numerous tentacles of extremely adhesive nature, and capable of being drawn back into little sheaths. Dr.

Willey has shown by observations upon living specimens that the Nautilus is able to creep by successive attachment of these tentacles (fig. 665), almost after the manner of a Star-Fish (see p. 90), though the apparatus employed in the two cases is of widely different nature.

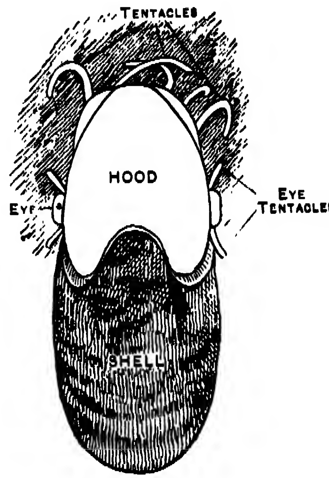


Fig. 665.—Pearly Nautilus (*pilius*) adhering to a smooth surface (reduced)

Animals of the cuttle-fish kind owe most of their peculiarities to specializations which they have undergone in relation to swimming (see p. 30), though there can be no doubt that the remote ancestors common to them and the other classes of molluscs were typical creeping forms. And living forms, such as Octopus and many of its allies, have found it advantageous to re-acquire the power of creeping, though still remaining good swimmers. One of these creatures is shown in the background of fig. 666 progressing in this way. The mouth being kept downwards, some of

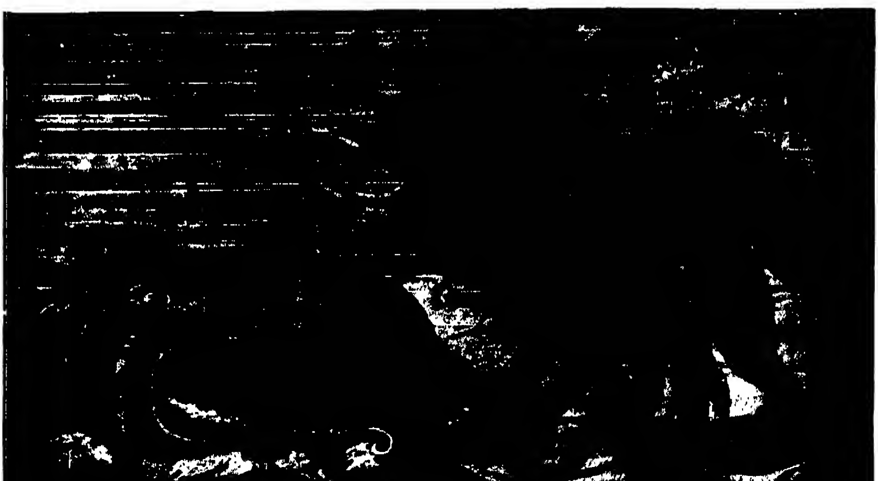


Fig. 666.—Common Octopus (*Octopus vulgaris*)

the sucker-bearing tentacles are extended in the desired direction, hold fast to the underlying surface, and then shorten so that the

body is dragged forwards. The comparison with a Star-Fish suggested for Nautilus is here much more appropriate, though the tube-feet of that animal are not only quite different in structure from the suckers of an Octopus, but are worked in a different way. And the comparatively rigid arms of the former animal are quite unlike the eminently flexible and highly muscular tentacles of the latter, which at one moment can be extended till they are no thicker than whip-cord, and at the next contracted into blunt broad projections.

The two individuals in the foreground of fig. 666 show characteristic resting positions.

CREEPING VERTEBRATES

The most remarkable creeping Vertebrates are SNAKES and other limbless Reptiles. Selecting the former for more detailed treatment, we find that the fore-limbs have disappeared altogether, and that at most the hind-limbs are represented by a pair of small projections, each of which may end in a little claw. More commonly, however, these extremities have completely vanished. The long cylindrical body is extremely muscular, and the ribs are extraordinarily numerous (fig. 667). The backbone is made up of a very large number of vertebræ, which are complex in nature, and united together in such a way as to permit of a large amount of movement, and yet at the same time to limit this to the extent necessary for the protection of the delicate spinal cord, any undue bending or stretching of which would result in partial or complete paralysis.

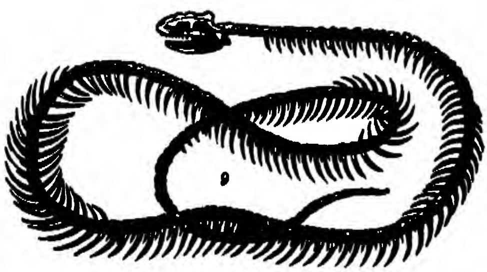


Fig. 667.—Skeleton of a Snake

Running along the under side of the body is a double series of large scales, the ventral shields, to which the ends of a corresponding pair of ribs are attached. The ribs are so hinged to the backbone that by means of appropriate muscles they can execute movements of considerable range. Whenever a rib is moved this way or that, the shield to which it is attached must

at the same time be brought into action, and this provides a mechanism for creeping. The result is a sort of undulation passing from one end to the other, and throwing the body into a series of horizontal curves. Putting it in a popular way, we may say that a snake walks on the tips of its ribs, or, more correctly, by means of the large scales to which these are fixed. A comparison may well be made with the mode of creeping previously

Fig. 668.—The Blind-Worm (*Anguis fragilis*)

described for Bristle-Worms (see p. 98), and while in these creatures a firm hold of the underlying surface with prevention of slipping is attained by means of bristles imbedded in the foot-stumps, the same advantages are secured in Snakes by the sharp hinder edges of the ventral shields.

Some of the Lizards have been modified in much the same way as Snakes, for which they are often mistaken, though careful examination shows that there is not quite so much specialization. Of such forms the harmless little Blind-Worm (*Anguis fragilis*, fig. 668), which is one of our few native reptiles, may be taken as a good example. It has elsewhere been pointed out (see vol. i, p. 225) that various existing lizards exemplify successive stages in this remarkable kind of specialization.

CHAPTER XLVI

MUSCULAR LOCOMOTION OF ANIMALS—WALKING, RUNNING, &c.

As a matter of practical convenience, Walking, Running, and closely-related ways of progression upon a firm surface, as distinguished from Creeping, are here considered as forms of locomotion limited to those animals that possess jointed limbs or appendages, which are attached to the body they support so as to allow of well-marked movement at the place of union. Examples of such limbs are presented by the legs of a quadruped, lobster, or insect, and the five slender "arms" which radiate from the body of a brittle-star, these being very different from the five arms of an ordinary star-fish. These appendages may be looked upon as so many compound levers, and in most cases the locomotion they effect is chiefly brought about by a backward push against the underlying surface, a sort of action of which the nature is readily understood by fixing our attention on what happens when we ourselves walk. Progression of this kind may take place either upon a horizontal or upon an inclined surface, but in the latter case there is a degree of steepness beyond which ascent is a matter of climbing, in which an essential part of the process consists in pulling the body forwards from in front, rather than in pushing it onwards from behind, though the latter commonly plays a part as well. Almost everyone knows from experience that slopes are often encountered in mountaineering which can only be negotiated by using arms as well as legs. In other words, walking gives place to climbing.

The word "walking" can further be only properly applied to modes of progression in which the moving animal is never completely "off the ground" or other underlying surface. Contact between the two is always maintained, though of course the points of contact are continually being shifted, old ones being replaced by new. In running, on the contrary, which is a swifter mode of

progression, the body leaves the ground for a fraction of time at every step. Jumping is effected in most cases by the sudden and vigorous straightening of well-developed hind-limbs, which push back against the ground with such force that the body is projected into the air.

Where typical walking and running are concerned the limbs employed are made up of several parts, which can be moved upon one another, and this greatly facilitates locomotion. In such modes of progression successive bending (flexion) and straightening (extension) of the limbs takes place, as a result of which much more effective pushes against the underlying surface can be given than would be possible if the extremities were stilt-like levers only movable at the place where they joined on to the body. Jumping, as briefly defined above, furnishes a very typical example of this. By carefully noticing what happens when we ourselves walk, run, and jump, the essential nature of the differences between these three methods of progression will be realized in a rough-and-ready fashion. In order, however, to gain detailed and accurate knowledge of what really happens during animal locomotion prolonged scientific investigations have been found necessary, in the course of which many ingenious kinds of special apparatus have been devised. The great improvement in photography which has taken place of late years has had much to do with the extension of our knowledge in this direction. A long strip of very sensitive film is moved at the rate desired through a camera by means of clockwork, and a series of photographs of a moving animal are taken upon it, thus enabling the exact nature of the movement to be determined. The eye alone is much too slow to detect all the details. By passing such a series through an optical lantern at a suitable speed, and projecting them upon a screen, the successive images fuse together and faithfully reproduce the movements as they appear to the eye. This is the principle of the well-known and much-appreciated cinematograph. Small portions of some such films are depicted on pp. 126, 136, 145, and 146.

WALKING

We will now first consider the not very typical walking, &c., of Brittle-Stars (*Ophiuroidea*) and certain Fishes (*Pisces*), afterwards dealing with the more ordinary cases presented by Amphibians

(*Amphibia*), Reptiles (*Reptilia*), Birds (*Aves*), Mammals (*Mammalia*), and Jointed-limbed Invertebrates (*Arthropoda*). Arthropods are left to the last because the numerous legs which they possess renders their movements difficult to understand, and also because they have not been investigated to the same extent as the backboned forms.

LOCOMOTION OF BRITTLE-STARS (OPHIUROIDEA)

In an ordinary Star-Fish the arms, usually five in number, which are present, cannot be regarded as limbs or appendages, but rather as prolongations of the body. As we have elsewhere seen (p. 90), their typical mode of locomotion is slow creeping, effected by innumerable tube-feet. The case is quite different in an ordinary Brittle-Star (fig. 669), for here we find a distinction between "body" and limbs or appendages. The former is disc-shaped, while the latter are five slender and very flexible arms, encased in four longitudinal rows of scale-like plates, one above, one below, and one each side. There is no longer, as in ordinary star-fishes, a groove on the under side of the arm, from which numerous tube-feet protrude. What corresponds to this groove is covered over by the series of plates which invests the under side of the arm (ventral plates). There are, however, little pointed structures which protrude on either side between the ventral plates and the adjoining lateral plates, but these can only by courtesy be styled tube-"feet", for they take no part in locomotion. The name "brittle"-star expresses the ease with which the arms can be detached from the body, an indication of their separate nature. And the scientific name of the group, Ophiuroidea (Gk. *óphis*, a snake; *oura*, a tail; *eidós*, form), expresses their resemblance to the tail of a serpent as to shape and also with reference to the writhing movements they can execute. Running along the centre of each arm is a series of calcareous pieces, which suggest the joints of a backbone both in form and the way in which they are united together. These have therefore been called vertebral

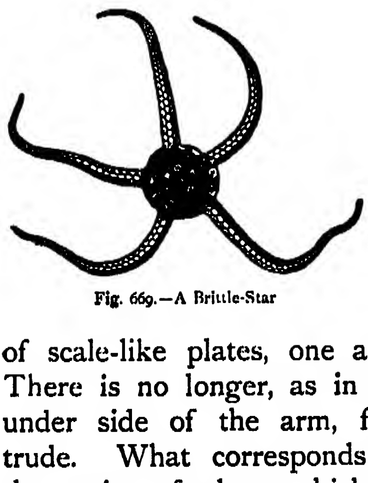


Fig. 669.—A Brittle-Star

ossicles. The resemblance is remote, for they are simply squarish blocks, and not nearly so complex as vertebræ. The presence and nature of these ossicles make the arms extremely flexible, and powerful muscle-bands attached to them bring about either simple bendings and straightenings, or curvings of complex character.

Romanes (in *Jelly-Fish, Star-Fish, and Sea-Urchins*) thus describes the locomotion of these creatures:—"The rays of the Brittle-Stars are very long, flexible, and muscular, and by their combined action the animal is able to shuffle along horizontal surfaces. When it desires to move rapidly, it uses two of its opposite arms upon the horizontal floor with a motion like swimming; at each stroke the animal advances with a leap or bound about the distance of two inches, and as the strokes follow one another rapidly, the Star-Fish is able to travel at the rate of six feet per minute. A common Star-Fish, on the other hand, with its slow crawling method of progression, can only go two inches per minute." In the more rapid kind of movement as thus described, one arm is kept pointing to the front.

LOCOMOTION OF CERTAIN FISHES (PISCES) UPON FIRM SURFACES

The above heading is purposely made rather indefinite, because the kind of locomotion to be dealt with is difficult to define.

The paired fins of an ordinary bony fish are flexible unjointed expansions, supported by firm rods (fin-rays), and chiefly useful in relation to swimming (see p. 41). In some few cases, however, they may be adapted to a kind of walking on the floor of the sea. In the Angler-Fish, for example (*Lophius piscatorius*, see vol. ii, p. 85), both pectoral and pelvic fins, equivalent to the fore- and hind-limbs of quadrupeds, are provided with powerful muscles, and can be employed for this purpose. A more remarkable instance is presented by Gurnards (*Trigla*), for part of each pectoral fin is modified into three finger-like projections, which can be turned forwards and used for walking. They have a curiously hand-like appearance.

The shore-haunting forms known as Mud-Skippers (*Periophthalmus*) (see vol. ii, p. 87) walk and spring with great facility, largely aided by their muscular pectoral fins, from the margins of which the hard tips of the fin-rays project, so as to give a firm

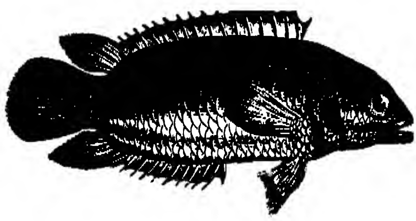


Fig. 670.—Climbing Perch (Anabas scandens)

They climb on to trees and large pieces of grass, leaves, and sticks, holding on by their pectoral fins *exactly as if these* were arms. *Now and then they plant these firmly as* organs of support, *the same as* one places one's elbows *on a table, then they raise their heads and take a deliberate survey of surrounding objects."*

As another example we may take the Climbing Perch (*Anabas scandens*) (fig. 670), which makes excursions on the land, forcing its way through vegetation. The strong pectoral fins appear to play an important part in this sort of progression, by hooking themselves round grass stems and the like, and pulling the fish forwards.

AMPHIBIANS (AMPHIBIA) AS WALKERS

Backboned animals (Vertebrata), with the exception of Fishes and still lower forms, are for the most part inhabitants of the land, and have become adapted to a terrestrial life by a series of evolutionary modifications that have gone on for an immense period of time. The original ancestral stock was undoubtedly aquatic, suited in all respects for life in water, and in the course of evolution many structures and organs originally adapted to an existence of this kind have of necessity undergone profound modification, to fit them for playing useful parts in fresh and widely different surroundings. Some of the problems which have been solved as regards organs of circulation and breathing have already been

dealt with (see vol. i, p. 244, and vol. ii, p. 421), and we have now to consider the evolution of structures related to the terrestrial locomotion of backboned animals.

In all questions connected with the evolution of land-vertebrates, the Amphibians are of singular interest. Not only do many of their characters clearly point to an aquatic ancestry, but also almost every member of the class in the course of its life-history presents us with an imperfect summary of the changes by which terrestrial vertebrates have sprung from aquatic forms, and we further know that this group is much older than those which include the other backboned animals that live on the land. Largely owing to this great antiquity, coupled with the fact that the skeletons of Amphibians are not well adapted for preservation in a fossil state, while of course the soft parts are not preserved at all, our knowledge of the origin of the group leaves much to be desired, and as Gadow says (in *The Cambridge Natural History*):—"The great gap within the Vertebrata lies between Fishes and Amphibia, between absolutely aquatic creatures with internal gills and 'fins', and terrestrial tetrapodous [*i.e.* four-legged] creatures, with lungs, and fingers, and toes".

LIMBS OF BACKBONED LAND-ANIMALS.—From what has already been said regarding the way in which a garden-snail creeps (p. 105) it will be realized that extensive contact with the underlying surface greatly retards progress, owing to the large amount of friction. And we have had occasion to note that certain snail-like animals have partly got over this difficulty by means of a sort of specialized creeping, during which the body is more or less lifted off the underlying surface. The evolution of walking-limbs has partly resulted from the necessity for raising the body so as to reduce the area of contact with the ground, which has also brought it to pass that such limbs have gradually become the chief agents of progression, and have consequently acquired a more or less complicated structure.

There can be no doubt that the fore- and hind-limbs of such a creature as a Newt or Salamander are strictly equivalent to the paired fins of a fish, *i.e.* the pectoral and pelvic fins, but it is not yet possible to speak with certainty as to the exact relation between the two. To put it another way—we feel assured that the remote ancestors of Newts and Salamanders were aquatic creatures possessed of paired fins much like those

of a fish, and that these fins gradually evolved into the fore- and hind-limbs as we now see them, but we are ignorant as to the intermediate stages between the two sorts of limb. It is usual to adopt some such view as the one embodied in fig. 671, which is copied from Wiedersheim, and which tentatively compares the pectoral fin of a shark with the fore-limb of a newt-like animal. In either case there is a strong shoulder-girdle (indicated by dotted lines) imbedded within the body, and to which the free part of the limb is attached. In the shark this is a firm but flexible three-sided paddle, the part of which next the body is supported by three pieces of gristle, and to these are attached a number of jointed rods or fin-rays, of which those near the under edge are particularly large and prominent. All these parts are shaded black in the figure. Turning now to the fore-limb of the land-animal we find that it is comparatively narrow, and evolution from the fish-fin may have brought about this narrowing by suppressing two of the large pieces of gristle and most of the fin-rays. The bone of the upper arm, *i.e.* the humerus, may be the equivalent of the remaining gristly plate of the fish, while the two bones of the fore-arm (radius and ulna), and the supporting structures of wrist and hand, may be the outcome of modification in the large fin-rays near the under edge of the shark's fin (see diagram), and of some of the smaller fin-rays in connection with these. A similar comparison can be instituted between a pelvic fin and a hind-limb. Although what has been said is probably true in a general sort of way, it is impossible to feel sure about any of the details. For one thing, the pectoral fin of a shark, though undoubtedly a fairly simple structure of its kind, may be very different from the pectoral fin actually possessed by the fish-like amphibian ancestors. It might be supposed that the Law of Recapitulation, according to which an animal or an organ in the course of its individual development passes through ancestral stages, would clear up the matter, and that by investigating the growth of a Newt's limb from the time of its first appearance onwards we could get an idea of all the

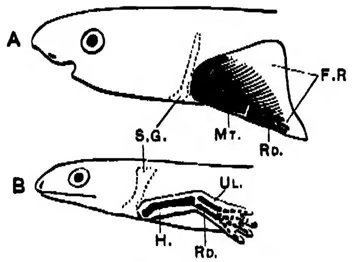


Fig. 671. Comparison between Fore-limbs of Fish (A) and Land Vertebrate (B)

S.G. Shoulder-girdle; MT. gristly plate at base of fin; RD. large fin-ray; F.R. fin-rays; H, humerus; RD. radius in B, large fin-ray in A; UL. ulna.

transitional stages between fin and limb. But this is by no means the case, for though the law in question affords valuable clues as to many matters, it is not of much use here, so far as at present known. It may be broadly true that the development of an individual animal is an epitome of the ancestral history of the group to which that animal belongs, but that is all we have a right to expect. For if an animal repeated in detail all the ancestral stages of its group before it became an adult, its development would take an inordinate time. It has to be fitted as quickly as may be for the stern realities of existence: hence a condensation, a skipping, and even a transposition of chapters in the family history, especially in cases where recapitulation might prove a danger during the early stages of life. This is the Law of Hastening of Events, and in the particular instance under discussion it comes into operation. The limb of a Newt does not begin as a fin-like structure which undergoes gradual modification, but is first a mere knob, which soon lengthens and quickly acquires the shape, proportions, and structure of the adult extremity.

The narrowness of a typical land-limb as compared with a fin is easily intelligible, for a paddle-like shape would not be suitable for the work which the former has to perform. The evolution of digits by the free projection of fin-rays presents no particular difficulty, for even some of the fishes, *e.g.* Gurnards (see p. 115), have converted some of their pectoral fin-rays into fingers.

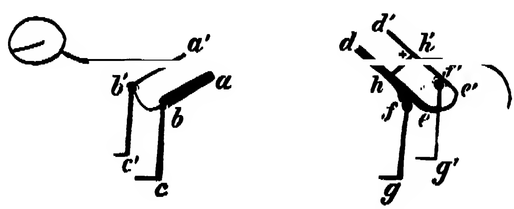


Fig. 672.—Diagram of Skeleton of Land Vertebrate

ab, *a'b'*, Shoulder-girdles united below; *bc*, *b'c'*, arms and hands; *dhe*, *d'h'e'*, hip-girdles united below, and with sacrum (*k*+*k'*) making up pelvis; *fg*, *f'g'*, legs and feet.

Another point is illustrated by fig. 672. A fish-fin is a simple lever, only movable where it is attached to the body; but the limb of a land-animal is a multiple lever, divided by transverse joints into a number of regions—upper arm, fore-arm, wrist, and hand in the fore-limb, corresponding to thigh, shin (or lower leg), ankle, and foot in the hind-limb. The importance of this has already been briefly indicated (see p. 113).

It is clear that walking- or running-limbs would not be able

to support and move the body with efficiency unless they were firmly united to it. For this reason that part of the limb-skeleton which is imbedded in the body is of great importance. In the case of the fore-limb this is called the shoulder-girdle, while in the case of the hind-limb it is known as the hip-girdle. The general character of these arrangements is represented diagrammatically in fig. 672. The two shoulder-girdles (*ab*, *a′b′*) are firmly united by muscle and fibrous tissue to the body, and are often united together in the middle line below (*b b′*), or connected with the

Fig. 673.—Crested Newts (*Molge cristatus*). Male above, female below

breast-bone when this is present (not shown in figure). The two hip-girdles (*d f e*, *d′f′ e′*) are much more intimately united with the body than this, for there is a more or less firm union between them and the backbone, by means of side projections from one or a larger number of vertebræ (*h* + *h′*) which constitute the sacrum. The two hip-girdles together with the sacrum are known as the pelvis. These two girdles are commonly united with one another below (*e e′*).

AMPHIBIAN LIMBS.—Taking a Newt (fig. 673) as an example, we notice that the sacrum is of very primitive nature, for it consists of but one vertebra. The fore- and hind-limbs do not lift the body well off the ground, which is slung as it were between those of the two sides, and both elbow and knee are outwardly directed. Hence as a limb is used it pushes against the ground, straightens, and gives a sort of shove, the

force of which partly impels the body onwards, but partly also moves it to one side. A Newt or similar creature consequently "wobbles" from one side to the other as it walks, and the result is to give the appearance of horizontal undulations. To put it popularly, the movement is rather "snaky". As in most cases of walking, the limbs are used *diagonally*, *i.e.* the two extremities of the same side do not move together nor in immediate succession, but the advance of a fore-limb is followed by the advance of the hind-limb diagonally opposite. We thus get this sequence—right fore-limb, left hind-limb, left fore-limb, right hind-limb, &c.

Though reduction of the area in contact with the ground is an important matter in the evolution of effective walking-limbs, such reduction can only reach a maximum where the underlying surface is hard and resistant. Amphibians live for the most part in marshy places, where the ground is soft and yielding, and the evolution of the walking-limbs of the group has taken place in relation to this condition. The extremities must therefore possess a sufficiently large walking-surface to prevent undue sinking into mud and the like, and, as might be expected, a Newt walks on the palms of its hands and soles of its feet, *i.e.* is *plantigrade*. Besides which, the fingers and toes spread out when they are pressed against the ground, thus giving an increased purchase. The typical number of digits in the limb of a land-vertebrate is five, as in the feet of most Amphibians; the hands of these creatures are four-fingered, though the vestige of a thumb is often found on dissection.

REPTILES (REPTILIA) AS WALKERS

What has been said about the walking of Amphibians is true in the main for Reptiles, but many of the latter are able to progress much more rapidly. There are some points of interest concerning Tortoises, Lizards, and Crocodiles which will now be considered.

TORTOISES (*Chelonia*).—In the section on Swimming we have had occasion to notice the interesting series of gradation which connect the walking-legs of the Land-Tortoises on the one hand with the flippers of Turtles on the other (see p. 54). It is with the former that we are here more specially concerned. The

stumpy limbs of an ordinary Tortoise project from within the shell, which partly encloses them. Owing to this, and to the fact that they have to support a considerable weight, they are brought more under the body than in Amphibians or average Reptiles, but this does not mean speed of progression, for the deliberate walk of a Tortoise is proverbial. The limbs are used diagonally as in Newts, &c. (see p. 121). Fore- and hind-limbs alike possess five digits, indicated by a corresponding number of blunt claws. The European Pond Tortoise (*Emys orbicularis*, fig. 674) will serve as an example of an early stage in the series of changes which lead on from these typical land-limbs to the paddles of Turtles. The digits are much more distinct externally than in Land-Tortoises, their claws are sharper, and webs extend between them. This is a double advantage, for it not only increases the surface used in swimming, but also prevents the animal from sinking into the mud when it walks under water, or on the margin of its native pond or stream.

Fig. 674.—European Pond Tortoise (*Emys orbicularis*)

Lizards (*Lacertilia*).—The limbs of an average form, such as our native Sand-Lizard (*Lacerta agilis*, fig. 675), are not unlike those of a Newt so far as the general proportions and relation to the body are concerned, but there are five claw-bearing digits on each hand and foot, instead of four on the former and five on the latter, all unprovided with claws. The Sand-Lizard, however, like most of its kind, is able to cover the ground with great rapidity, and in this particular animal the specific name "agilis" is well chosen, for the little reptile is by no means easy to catch, and makes its way through grass or

heather with astonishing celerity. So far as mere speed is concerned, it may be said to run, but as the body never entirely leaves the ground the word is not strictly applicable.

Fig. 675.—Sand-Lizard (*Lacerta* ι

Some few Lizards are able to walk upon their hind-legs, of which the most remarkable example is the Frilled Lizard (*Chla-*

Fig. 676.—Frilled Lizard (*Chlamydosaurus Kingi*)

mydosaurus Kingi, fig. 676) of Australia, a powerful form which attains a length of about three feet. Should danger threaten, it

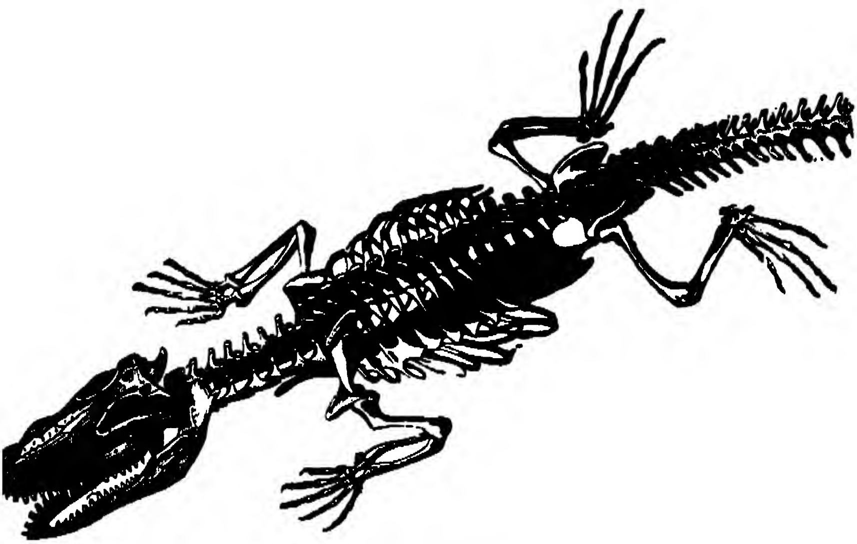


Fig. 677.—Skeleton of Crocodile

which elbows and knees stand out at the side, and the structure of the hands and feet, will be gathered from fig. 677. Cyrus W. Butler (in *The Big Game of North America*) speaks as follows regarding the mode of progression of the Alligator (*Alligator Mississippiensis*):—"In their common walk the central surface just clears the ground, and the end of the tail drags so as to leave a sharp cut in the mud between the footprints. But, when necessary, the Alligator can arch his back, straighten his legs so as to raise his body some distance from the ground, and shuffle off at a surprising gait. As a rule he seldom goes far from water, and when he does, it is in travelling from one body of water to another."

BIRDS (AVES) AS WALKERS AND RUNNERS

Since the fore-limbs of Birds are modified into wings, it of course follows that these animals must progress on land in a two-legged or bipedal fashion, as do we ourselves. But the walking of a typical bird differs in several respects from the walking of a man, the anatomical relations between trunk and hind-limbs being very dissimilar in the two cases. For in human beings the long axis of the body is vertical, and its weight is supported on a strong basin-shaped pelvis, formed by union of the two hip-girdles with a broadened part of the backbone known

Fig. 678.—Grey Wagtail (*Motacilla melanope*)

as the sacrum (see vol. i, p. 27). In Birds the attachments of the legs are, so to speak, shifted forwards, and the body is balanced between them, its long axis being oblique (fig. 678). The two hip-girdles are of extraordinary length, extending far in front of the hip-joints as well as a long way behind them, an arrangement which gives a very extended surface for attachment to the backbone. The corresponding region of the latter (sacrum) is formed by the fusion of a larger number of vertebræ than in any other class of vertebrates. Great firmness is thus secured, which is all the more necessary as the two hip-girdles do not, as a rule, unite with one another below, as is the case in Amphibians, Reptiles, and Mammals. If these girdles were not, therefore, very firmly fixed to a long piece of the backbone, a bird would walk or run in a very unsteady way, giving it a poor chance of escaping from enemies without having recourse to flight. There is also a remarkable peculiarity in the construc-

tion of a bird's leg, for the ankle-joint is not situated, as in a human being, between the shin-bone and the ankle-bones, but in the middle of the region which the latter support. A bird walks on its toes, of which never more than four are present, one (the great toe) being usually turned backwards, and the others forwards. It is therefore "digitigrade", like a cat or lion, and the instep region is upwardly directed, the ankle-joint being therefore lifted off the ground. The presence of a number of little ankle-bones would clearly tell against firmness under these circumstances, and so would the existence of several separate instep-bones. It is, therefore, not surprising to find that a good deal of fusion has taken place (fig. 679). The upper part of the ankle-skeleton (tarsus) has united with the lower end of the shin-bone (tibia) to form what is technically called the "tibio-tarsus", while the lower part of the ankle-skeleton and three instep-bones (metatarsus) have all united together into the "tarso-metatarsus", or shank-bone. Although these two words are long and clumsy, they are extremely lucid, and quite easy to understand if we remember that tibia, tarsus, and metatarsus are the scientific words for shin-bone, ankle-bones, and instep-bones. From what has been said it will be clear that the body of an ordinary land-bird is raised much further from the ground than is the case with a newt or lizard, and the limbs are more under the body, which successively rises and falls during progression.

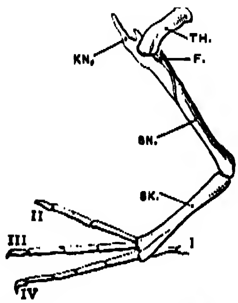


Fig. 679.—Bones of a Bird's Leg
TH., Thigh-bone; F., fibula; KN., knee-cap; SN., shin-bone; SK., shank-bone; I–IV, toes.


Fig. 680.—Series of instantaneous photographs of a Hen walking. Read from top to bottom.

In spite of the great difference as to structure, the legs of a bird are used in walking much in the same way as those of a human being. They are alternately swung to the front, and the body falls on to each of them in turn, so to speak. This is very well illustrated by fig. 680,

which represents part of a series of photographs taken of a hen in the act of walking.

Birds which wade, or walk about in marshy places, often have long, stilt-like legs, which enable very long steps to be taken, and are of advantage in other ways, *e.g.* they confer on their owner a power of extended observation. The White Stork (*Ciconia alba*) (fig. 681) is a good instance of this. The toes of such birds are long and spreading, so as to prevent sinking into the soft under-

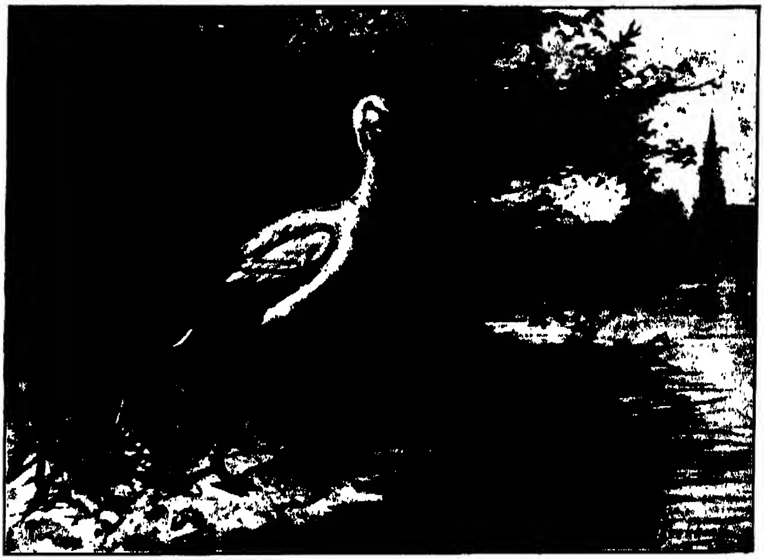


Fig. 681.—White Stork (*Ciconia alba*)

lying surface, and in many cases the same end is furthered by the presence of webs between the toes, or of membranous expansions which answer the same purpose. This is illustrated by fig. 682, which represents the feet of several members of the Plover group which frequent places where the ground is soft. On the left is seen the foot (*a*) of a Common Snipe (*Scolopax gallinago*), with strong spreading toes. This bird lives in marshy spots, and the legs are not very long. The Common Sandpiper (*Totanus hypoleucus*) haunts shores and inland waters, and its toes are webbed at the base (*b*). The digits of the Grey Phalarope (*Phalaropus fulicarius*), a shore form, are lobed (*c*). Those of the long-legged Avocet (*Recurvirostra avocetta*) are fully webbed (*d*), and this gives a sure footing while the bird is wading in shallow water or tide-pools, searching for food. This chiefly

consists of small crustaceans, &c., which are scooped up from the sand by the long, slender beak, the end of which is bent sharply upwards. Phalaropes and Avocets are expert swimmers, and the structure of their feet is related to this as well as to use on a soft underlying surface.

The extremities of some few birds are well adapted to scrambling over the floating leaves of water-lilies or other aquatic

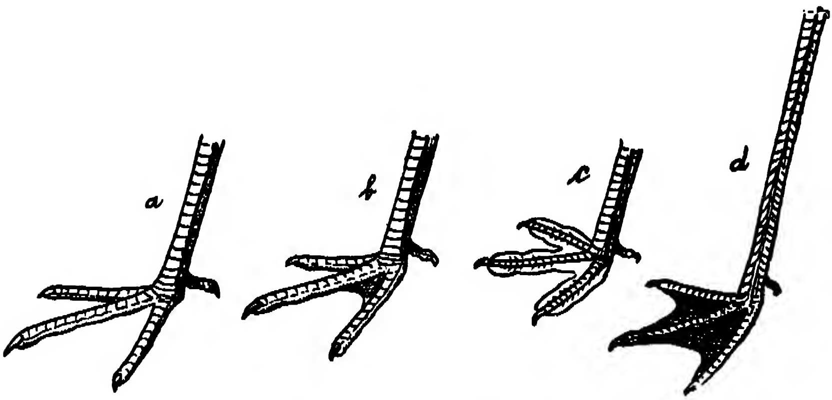


Fig. 682.—Feet of Plover-like Birds

a, Snipe (*Scolopax gallinago*); *b*, Sandpiper (*Totanus hypoleucus*); *c*, Grey Phalarope (*Phalaropus fulicarius*); *d*, Avocet (*Recurvirostra avocetta*).

plants, and this is said to be one of the uses of the lobed toes of the Coot (see p. 61). But the most remarkable arrangement of the kind is found in the Jaçanas, which inhabit parts of South America, Africa, South Asia, Australia, and New Guinea. The long and slender legs are supported by four toes of quite extraordinary length. A well-known species is the Water-Pheasant or Jaçana (*Parra jacana*) (fig. 683), which ranges from Guiana to Argentina.

Running Birds.—Existing Birds are divided into two groups, the Runners (*Ratitæ*) and Flyers (*Carinatæ*), of which the latter include the vast majority of species. These names are only appropriate in a general sort of way, for though none of the Runners can fly, many of the Flyers can run, while some of them have lost the power of flight, *e.g.* Penguins.

It is, however, undoubtedly true that the Ostriches, Emeus, &c., which together constitute the Ratite group, are the most expert runners in the class of Birds, and this is intelligible when we remember that their wings are so small and reduced as to be

useless for flying purposes, and they therefore have to rely on legs alone.

The swiftest runners among both Birds and Mammals have several characters in common, resulting from their adaptation to easy and rapid locomotion upon a firm or fairly firm surface.

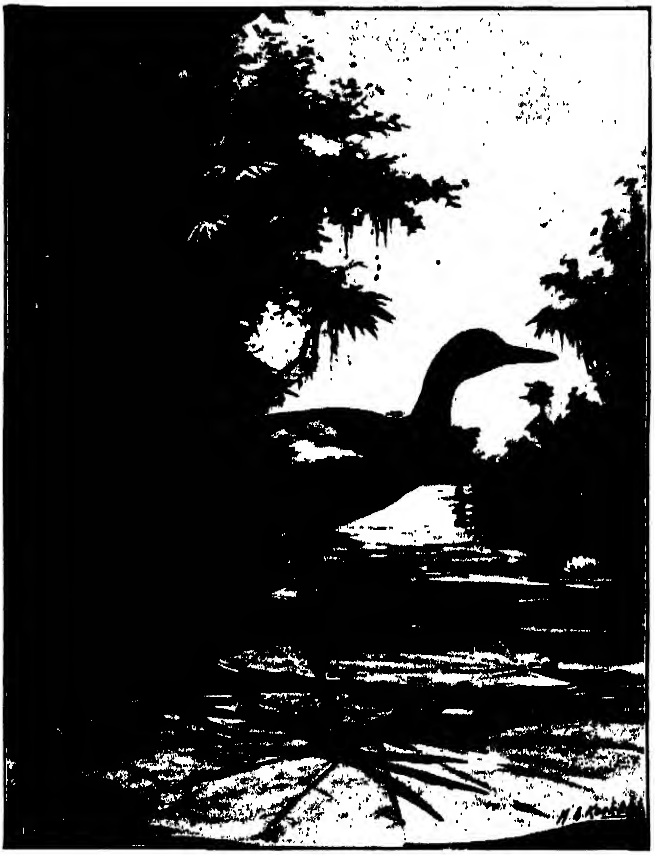


Fig. 683.—Jaçana (*Parra jaçana*)

Both in an Ostrich and a Horse the legs are extremely powerful and of great length, while at the same time they are placed well under the body, which prevents "wobbling" from side to side, as this would wastefully expend more or less of the muscular force exerted. Effective length of limb is partly gained in both cases by the body being raised as it were on tiptoe. It is further obvious that, given a firm surface, the successive pushes against the ground which bring about walking or running can be

most effectively given when the pushing parts are of compar tively small size in comparison to the weight of the body. Th end has been gained both in Ostrich and Horse by a reduction i the number of toes. The latter presents an extreme case of th *kind, for all the digits have disappeared except the 3rd or midd one. Of all Ratite Birds the African Ostrich (Struthio camelus is undoubtedly the swiftest, and when at full speed is said to take strides of 25 feet in length, and to easily outdistance a galloping horse. But in hunting it down, advantage is taken of the curious fact that it does not travel in a straight line,* but in a curve. In correspondence with this great speed we find that the Ostrich has fewer toes than any other bird, only two being present (fig. 684). It is usual to number the digits 1, 2, 3, 4, 5, of which the first or great toe is the inner one. In an ordinary 4-toed bird the 5th has disappeared, but in the Ostrich two more have gone, the 1st and 2nd, leaving only the 3rd and 4th, of which the former is much the larger. Reduction in number of a series of organs commonly means an increase in size of those remaining, and this is the case here. Both toes are very stout, and their under sides are provided with thick pads, so as to prevent them from sinking into the sand.

Fig 684.—Left Leg of African Ostrich (*Struthio camelus*), seen from outer side

There are but two toes, 3rd and 4th, of which the former is the larger.

The feet of American Ostriches (*Rhea*) are similar in structure, but reduction has not gone so far, for three toes are present, *i.e.* the 2nd, 3rd, and 4th. These birds are also very swift runners. The Emeus (*Dromæus*) and Cassowaries (*Casuarius*, fig. 685) of the Australian region are also three-toed, but the little Kiwis (*Apteryx*) of New Zealand possess the usual four digits, though the 1st or great toe is small, and, being raised from the ground, does not assist in locomotion.

The wings of Running Birds, though too much reduced to

be of use for purposes of flight, would appear to help rapid progress on the ground. On this point Pettigrew speaks as follows (in *Animal Locomotion*):—"The wings of the Ostrich, although useless as flying organs, form important auxiliaries in running. When the Ostrich careers along the plain, he spreads out his wings in such a manner that they act as balancers, and so enable him to maintain his equilibrium. The wings, because of the angle

Fig. 685.—Cassowary (*Casuarius*). Three toes are present, 2nd, 3rd, and 4th

of inclination which their under surfaces make with the horizon, and the great speed at which the Ostrich travels, act like kites, and so elevate and carry forward by a mechanical adaptation a certain proportion of the mass of the bird already in motion. The elevating and propelling power of even diminutive inclined planes is very considerable when carried along at a high speed in a horizontal direction. The wings, in addition to their elevating and propelling power, contribute by their short, rapid, swinging movements to continuity of motion in the legs. No bird with large wings can run well. . . . What, therefore, appears a defect in the Ostrich is a positive advantage when its habits and mode of locomotion are taken into account."

In African and American Ostriches the two hip-girdles are not only firmly united with the backbone, but also to some extent with one another, and the pelvis is thus firmer than in other birds. It may further be noted that in all Ratite forms, except Kiwis, many of the bones contain large air-spaces, giving a combination of strength with lightness which probably has relation to the great powers of locomotion.

MAMMALS (MAMMALIA) AS WALKERS AND RUNNERS

Although Land Mammals differ very much among themselves as regards powers of progression, they are on the average the best endowed quadrupeds in this respect, being far superior to Amphibians and Reptiles. This is largely due to the greater activity associated with relatively efficient circulatory and breathing organs. All parts of the body are provided with well oxygenated blood of constant and comparatively high temperature (about 98° F.), in which respect the cold-blooded Amphibians and Reptiles are not nearly so well off.

The well-nourished muscles which constitute the primary agents of locomotion are highly specialized, and the skeleton to which these are attached presents a number of mechanical arrangements which are directly related to efficient walking and running. Some of these will be gathered by reference to fig. 686, which represents the skeleton of a Dog.

As might be expected, the limbs are very firmly united to the trunk. The shoulder-girdle chiefly consists of the triangular shoulder-blade (scapula), which is firmly bound to the body by powerful muscles. In many Mammals, *e.g.* Man, each shoulder-girdle also includes a collar-bone (clavicle), stretching from scapula to breast-bone (sternum), and thus a transverse connection is established between the two girdles below. But in Dogs, Horses, and other forms able to run very rapidly, the collar-bones are either entirely absent (horse) or reduced to unimportant vestiges (dog). Why they have undergone such reduction is easily understood. Their presence would seriously hamper the forward and backward movements which have much to do with speed, and they would also be liable to fracture, as a result of the sudden strains brought to bear upon them during running, at the moment when the body suddenly alights upon a fore-limb.

In the skeleton of the hind-limb we notice that the two hip-girdles are closely united to part of the backbone (sacrum), in which several vertebræ immediately behind the region of the loins have fused together. This union is not so extensive as in Birds (see p. 125), which have to walk or run on two legs only, but on the other hand added stability is gained in the Mammal by fusion of the two hip-girdles together below. It must be admitted that this extremely firm connection of hind-limbs with body reduces to some extent the range of forward and backward movement in the legs, but this is more than counterbalanced by the gain in steadiness, and there is not the same liability to sudden shocks as is the case with the shoulder-girdles. For when a running animal, after a moment's suspension in the air, comes down on a fore-limb, it is obvious that the forward nature of the movement imposes a greater stress than when a hind-limb comes down first. No doubt, even in this case, a very considerable shock is experienced, but the pelvis (*i.e.* hip-girdles plus sacrum) is exceedingly strong, and built on the principle of the arch.

Turning to the parts of the limbs below shoulder- and hip-joints (see fig. 686), we see that these, especially the hinder ones, are relatively long, and lift the body well off the ground. During progression the limbs move practically from front to back, comparatively little force being wasted in side-pushes, as is the case in Amphibians and Reptiles (see p. 121), where the body is slung between the limbs, with both elbows and knees directed outwards. The mammalian arrangement is clearly better adapted to effective walking or running, during which the body moves up and down in a wavy vertical curve, and does not present the horizontal undulations so characteristic of quadrupeds lower in the scale.

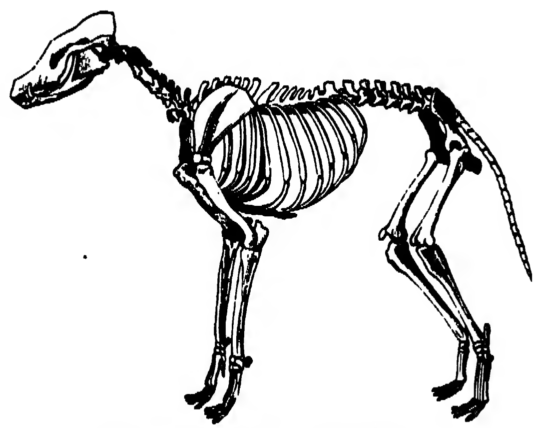


Fig. 686.—Skeleton of Dog. Described in text

In the Dog, and other Mammals possessed of great speed, there

are well-marked angles between the several sections of the limbs, *e.g.* the elbow is directed well backwards and the knee well forwards. A double purpose is served by this arrangement, for the limbs are thereby converted into shock-reducing springs, while at the same time their sudden straightening enables powerful and effective backward pushes against the ground. This is particularly true for the hind-limbs, since these do much more work in a running animal than the fore-limbs, as necessarily follows from the fact that this kind of locomotion depends upon vigorous pushes against the ground, which are of course made with greatest effect from behind. This is one reason why the hind-limbs are so firmly united to the trunk, and the liability to shock which results from this is largely discounted by the conversion of these limbs into springs.

The amount of swing which the limbs can execute must not be judged from their length as seen in the skeleton, for in swift runners the upper arm and thigh are more or less imbedded in the trunk, and surrounded by the skin which bounds that region. This is to some extent the case in the Dog, but is still more marked in such creatures as the Horse. Union of limbs with trunk is thus rendered very intimate. But in these particular animals the shortening entailed by this is made up for by the length of the bones in the sections of the limbs below elbow and knee, and especially by the fact that the body is supported on the digits, *i.e.* the position is *digitigrade.* The palm-bones (metacarpus) and instep-bones (metatarsus) are almost vertical, so that wrist and ankle are lifted well off the ground. We have already seen that this is also true for Birds (see p. 126).

In cases where limbs are chiefly or mainly used for walking or running, it is clearly advantageous that their supporting skeleton should be made as strong and simple as possible. This has been more or less brought about by the firm union, or even fusion, and also by the reduction of certain bony elements. Both forearm and lower leg contain two bones—radius and ulna in the former, tibia and fibula in the latter. In running Mammals there is a marked tendency for radius and tibia, *i.e.* the two which have the larger surface of union with hand and foot, to increase in size, while the ulna and fibula dwindle to a corresponding extent. This is also true for the leg of a bird, in which (see fig. 126) the fibula is very small. In the case of

the Dog this process has not affected the fore-limb, which is used for many purposes besides progression, but in the hind-limb the tibia is distinctly larger than the fibula, which is firmly united, but not fused with it. In this animal, too, the reduction of digits already noted in running birds (see p. 130) is beginning to take place, for the thumb is relatively small and does not reach the ground, while the great toe is usually only represented by a vestige. A comparatively primitive Mammal such as a Hedgehog has five fingers and five toes, *i.e.* is *pentadactyle*, while a dog has but four of each for locomotor purposes, *i.e.* is practically *tetradactyle*.

It is out of the question to attempt here any description of the immensely complicated muscular mechanism by which walking and running are effected, but we may well agree with the words of Graber, where (in *Die Werkzeuge der Wirbeltiere*) he compares the muscles of the body with the complicated ropes of a sailing-ship or the power-bands of a factory:—". . . the rigging of a sailing-ship, or the moving, power-transmitting bands of a large factory provided with numerous motors, appear to the lay mind as a bewildering arrangement. But if we look at all the muscles which cover and surround the backbone and limbs of vertebrates, we cannot but realize that the mechanical devices mentioned appear as children's toys when compared with the muscular machinery of backboned animals."

Fig. 687.—Bones of Hind-leg of a Bear, from the knee downwards. The foot is plantigrade

Many Mammals which are not so specialized as Dogs or Horses in regard to rapid progression, walk on the palms of the hands and soles of the feet, *i.e.* are *plantigrade*. It is inferred, from what is known of living and extinct forms, that this was the case in the earliest evolved members of the class. The more efficient digitigrade attitude is a later development, gradually acquired by forms to which considerable speed was a necessity, either for pursuit of prey, as in many of the Flesh-eating Mammals (Carnivora), or as a means of escape from enemies, as in the majority of Hoofed Mammals (Ungulata). Bears are typically plantigrade forms, and the bones of the lower

part of the hind-limb are represented in fig. 687 to illustrate this. Compare also the drawing of Brown Bears given on p. 155.

Fig. 688. – Series of instantaneous photographs of Dog walking. Read from top to bottom

Having considered at some length the structure of the skeleton of the Dog (*Canis familiaris*) taken as a type, it will be convenient to consider the order in which the limbs of this animal are moved during walking. The same method is exemplified here as the one already described for Amphibians and Reptiles (p. 121), *i.e.* the limbs diagonally opposite succeed one another in their forward movement. Beginning, say, with the right fore-foot, the sequence is—right fore-foot, left hind-foot, left fore-foot, right hind-foot. Part of a series of photographs of a walking dog is given in fig. 688 to illustrate the movement of the right fore-foot. Beginning at the upper end and passing downwards, the way in which this extremity is brought to the front will readily be realized.

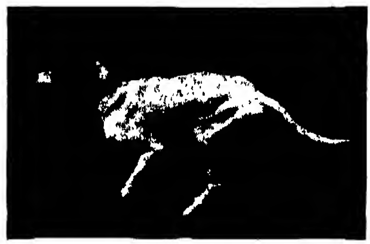


Fig. 689.—Instantaneous photograph of Dog running

To illustrate the nature of running in Mammals the Horse will be considered further on, as so many observations have been made upon it that no better example could well be selected. As to the way in which a dog runs, it need only be remarked here that, as in all other cases of this sort of progression, the body is completely off the ground for a very short time at regular intervals. Fig. 689 is an instantaneous photograph of one of the positions assumed, and shows the body resting on the hind-feet, while the fore-feet are preparing to move forwards, and it is clear from their positions that they reach the ground at different times. That the hind-limbs have a considerable forward swing is obvious from the fact that they overlap the fore-limbs. Although the body rests on both hind-feet for the

time being, the photograph shows that they do not work exactly together, or the right hind-limb would not be seen at all. Parts of it, however, are visible, owing to the fact that the left hind-limb is strongly bent. Its sudden straightening will give the body a vigorous forward push. The various joints can also be made out in the figure. In the fore-limb the elbow is directed backwards and the wrist forwards. Exactly the reverse is true for knee and ankle in the hind-limb. The position of the tail suggests its use as a balancing organ.

The more interesting cases of walking and running of members of some of the orders of Mammals will now briefly be reviewed.

HOOFED MAMMALS (*Ungulata*).—It will be convenient first to consider the Odd-toed Ungulates (Perissodactyla), so called in reference to the number of digits on the *hind*-foot, afterwards passing on to the Even-toed Ungulates (Artiodactyla). Most living species of these groups are characterized by the fact that they are entirely supported on the firm, horny hoofs which cover the end-joints of the digits, and this may be regarded as the most extreme case of digitigrade progression. The term *unguligrade* (*i.e.* hoof-walking) is employed to express it. Reference to fig. 693 will show exactly what is meant. Some few forms, however, cannot be so described, as will be seen in the sequel.

Odd-toed Ungulates (Perissodactyla).—The three groups of forms which these embrace—Tapirs, Rhinoceroses, and Horses—constitute a series of increasing specialization as regards locomotor organs.

Tapirs (fig. 690) are comparatively short-legged and rather clumsy animals, native to south-east Asia, South America, and Central America. Most of them live in dense, marshy forests, where there is not the same necessity for speed as in more open country. The wrist- and ankle-joints are lifted well off the ground, and the latter are well seen in fig. 690 at the back of the hind-limbs. For animals which constantly walk over yielding ground it is clearly necessary that the area of the surfaces of contact should not be too small (see p. 121). In Tapirs, although a reduction of these has resulted from the raising up of the palm and instep regions, this is to some extent made up for by the spreading nature of the toes, of which all the hoofs touch the ground. The full complement of digits (five), however, is not present, for there are but four in front and three behind.

It is the rule for Mammals that when such reduction takes place the 1st or innermost digit (thumb or great toe) first disappears, and then the 5th or outermost one (little finger or little toe). This is the case in Tapirs, which have lost thumb, great toe, and little toe. It is further to be noticed that the loss of certain digits is associated with increased size of those which remain, and in most Odd-toed Ungulates the central finger or toe (3rd) gradually becomes very large and dominant,

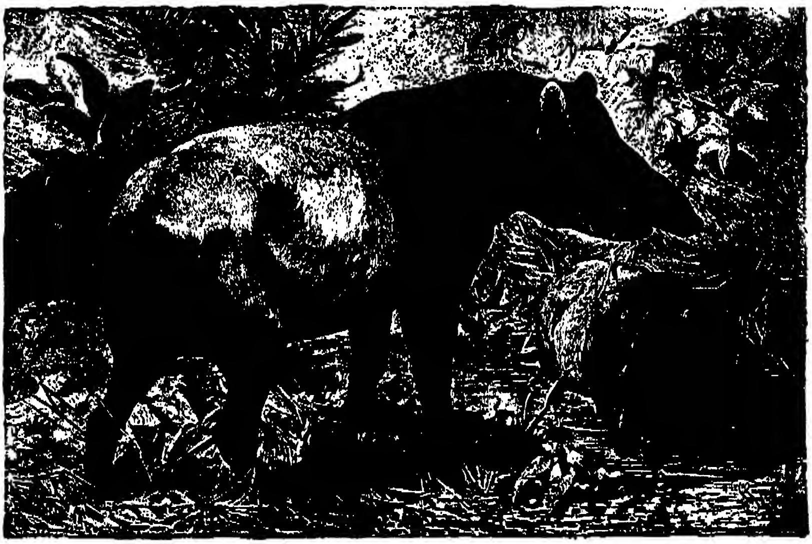


Fig. 690.—Malayan Tapir (*Tapirus Indicus*)

being also symmetrical in itself, a feature presented by none of the Even-toed Ungulates. This is, indeed, a much more distinctive character of the two groups than the mere number, odd or even, as the case may be, of the toes on the hind-foot.

Rhinoceroses (fig. 691) are such powerful and well-protected animals that they have but few serious enemies, and adequate support of the massive body is a more pressing necessity than speed in progression, especially as some of them inhabit marshy forests or grassy jungles, where the ground is yielding. The last remark is more particularly true of the Asiatic species, but the African forms live in more open country. Of these the White Rhinoceros (*Rhinoceros simus*) inhabits grass-covered steppes, while of the Common or Black Rhinoceros (*R. bicornis*) Sir Samuel Baker states (in *Wild Beasts and their Ways*):—" I

have never found the African Rhinoceros in the neighbourhood of swamps, but, on the contrary, I have generally met them in dry and elevated places, at the base of rocky hills, or in woods, at some distance from a river". But at regular intervals these creatures also are obliged to step on yielding surfaces, at the times when they go to drink at streams or ponds.

The limbs of a Rhinoceros are comparatively short, while in shape they are stout and pillar-like. Reduction of digits has gone further than in Tapirs, for little finger as well as thumb

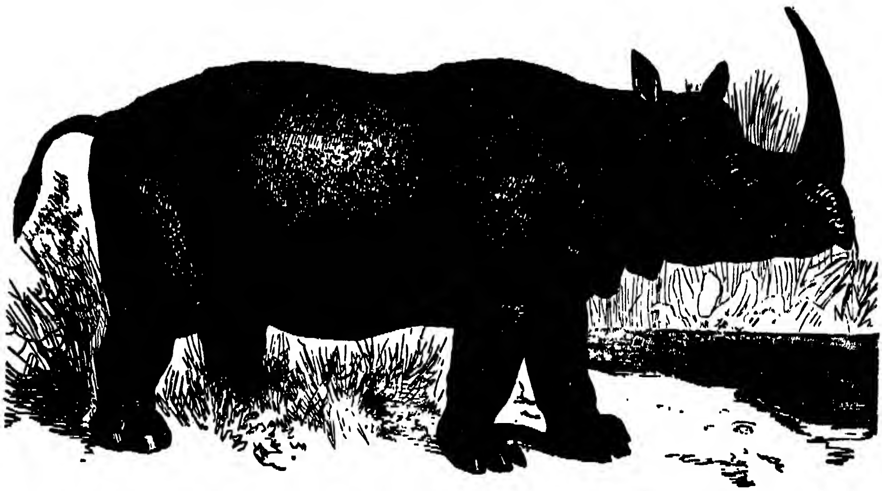


Fig. 691.—Indian Rhinoceros (*Rhinoceros unicornis*). Note the three-toed feet

has been lost by the hand, so that both fore- and hind-feet are three-toed (*tridactyle*). It may appear a little inconsequent to speak of the hand as a fore-"foot", and especially to use both terms in the same sentence. But in comparison of fore- and hind-limbs as regards digits it is more correct to use the words "hand", "fingers", "foot", "toes", and obviates clumsy expressions such as "fore-little-toe" and "hind-little-toe", while, on the other hand, it is obviously convenient when dealing with walking and running extremities to give the words "legs", "feet", and "toes" a wider meaning, and apply them indifferently to both pairs of limbs.

The third or central digits of a Rhinoceros are not markedly larger than the others, perhaps because in the case of such a heavy animal a uniform distribution of pressure is necessary. Nor is this creature a true hoof-walker, for the weight of the

body is largely borne by large hard pads placed on the under sides of the palm- and instep-regions.

It must not be concluded from what has been said that Rhinoceroses are distinguished by great slowness of gait, for although the limbs are so constructed as to give a remarkably firm support, they are at the same time capable of vigorous and rapid movement, and the twelve hoofs present can accommodate themselves to irregular surfaces better than the four hoofs of a horse, which are better suited for swift progression on even ground. Speaking of the Black Rhinoceros (*R. bicornis*) Sir Samuel Baker gives a vivid picture (in *Wild Beasts and their Ways*) of the possibilities in this direction:—"When the vast bulk of a Rhinoceros is considered, it is astonishing to see the speed that this heavy animal can attain, and continue for a great distance. I have hunted them in company with the Arabs, and for at least two miles our horses have been going their best, keeping a position within five or six yards of the hind-quarters, but nevertheless unable to overtake them before they reached an impenetrable jungle. It is the peculiar formation of the hind-legs which enables the rhinoceros to attain this speed; the length from the thigh to the hock [*i.e.* ankle-joint] is so great that it affords immense springing capacity, and the animal bounds along the surface like a horse in full gallop, without the slightest appearance of weight or clumsiness. Upon a level plain, free from bushes or stones, a good horse would quickly overtake the Black Rhinoceros, but the animal is seldom found upon such favourable ground, and its strength and three-hoofed feet give it a peculiar advantage for travelling at a high speed over a rough surface that would test the endurance of the best horse."

Horses and their immediate allies are by far the most specialized of the Odd-toed Ungulates, and their powers of locomotion would appear to have been evolved with reference to rapid progression on even and tolerably firm tracts of country. The general proportions of the body, and the relation of the long limbs to the trunk, are clearly seen in fig. 692, and it will be observed that upper arm and thigh are largely merged in the latter. As a result of this the elbow and knee are very high up, and the so-called "knee" of a horse is really the wrist, while the "hock" is the ankle. A little way above each foot is a projection known as the "fetlock", on which grows a tuft

of hair to which the name is also sometimes applied. This marks the position of a knuckle-joint in the fore-foot, and its equivalent in a hind-foot. It therefore follows that the long sections of the fore- and hind-limbs, situated respectively between "knee" and fetlock and "hock" and fetlock, correspond to the palm-region of the hand and the instep-region of the foot in, say, a man. The hind-limbs are obviously longer and stronger than the fore-limbs, and even in a resting attitude

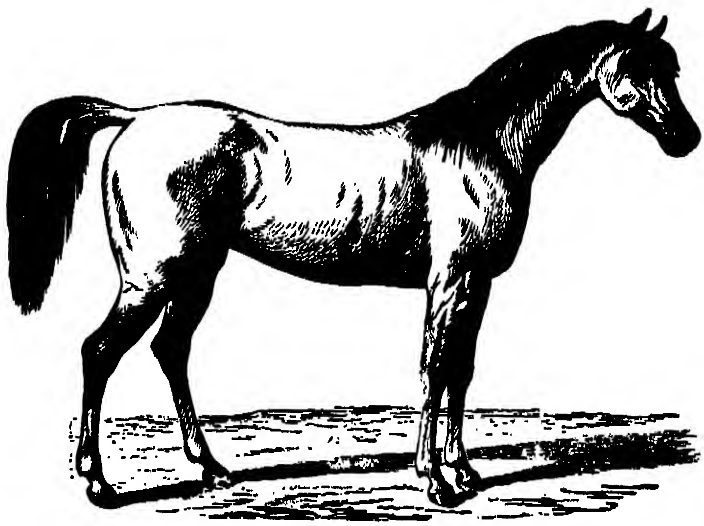


Fig. 692.—Horse (*Equus caballus*). Note the one-toed feet

(fig. 692) present well-marked bends. Reference to fig. 696 will show where all the joints come in both fore- and hind-limbs.

Turning now to the skeleton of the Horse's limbs, we find that the fore-arm and lower leg are mainly supported by one bone, radius or tibia as the case may be, while the other bone of the same region (ulna and fibula) are correspondingly reduced. Wrist and ankle include a number of small bones, an arrangement first evolved in the interest of flexibility. But in a case like this, where these regions are lifted off the ground, firmness is more necessary than flexibility, and this is provided for in more than one way. By means of firm, fibrous bands known as ligaments, the wrist- and ankle-bones are very firmly united together, and the members of the two tiers which are present alternate with one another (see fig. 701), like two successive rows of bricks in a wall. This "bonding" obviously makes wrist and

The sections of the limbs which are situated between wrist and fetlock and ankle and fetlock contain the so-called "cannon-bones", which are simply the palm-bones of the middle or third digits in the fore-limb, and the instep-bones of the same digits in the hind-limbs (fig. 693). The region below the fetlock is supported by three bones, of which the lowest is greatly broadened for the attachment of the hoof. These complete the skeleton of the third digits, which are the only ones fully developed. The Horse is, in fact, one-toed or ***unidactyle***. Reduction has gone a stage further than in the Rhinoceros, which is three-toed, and has retained the 2nd, 3rd, and 4th digits on each foot. By loss of the 2nd and 4th, with retention of the 3rd, the condition presented by the Horse would be reached. At this point we naturally enquire whether any traces of the 2nd and 4th digits are present in the skeleton of a horse's foot. The answer is in the affirmative, for lying on either side of the cannon-bone a narrow "splint-bone" is to be seen (fig. 693). These splint-bones are no other than the dwindled remains or "vestiges" of these two lost digits, corresponding to their palm-bones in the hand, and their instep-bones in the feet. We therefore conclude that the Horse was once, like the Rhinoceros, three-toed, and this conclusion is borne out by the facts of development, and by the study of extinct fossil forms.

Fig. 693.—Bones of Left Hind-foot of Horse, seen from outer side

t, Shin-bone (tibia); *a*, pulley-bone (astragalus) of ankle. *ca*, heel-bone (calcaneum); III, instep-bone of large middle toe;

In the preceding parts of this book mention has several times been made of the Law of Recapitulation, according to which the development of an individual animal may broadly be taken as an epitome of the evolutionary history of the group to which it belongs. In this particular instance it has been shown by Cossar Ewart that each limb of a young unborn foal possesses a pair of

little projections or "buttons" near its lower end, one on either side. There can be no doubt that these small knobs represent the tips of the 2nd and 4th digits.

Geological testimony is still more emphatic. A long series of fossil horses, or rather horse-like creatures, is now known, which proves conclusively that there has been a gradual reduction of digits, associated with other specializations, culminating in the forms which now exist. The hands and feet of some of these extinct creatures are shown in fig. 694, with the corresponding parts of a horse at the top for comparison. In the oldest form there represented (at the bottom) we see that there were four digits on the hand and three on the foot, *i.e.* the condition now found among Tapirs. The gradual dwindling of ulna and fibula is also indicated in the figure. Horse-like animals have been getting larger and larger during the progress of these various modifications. The oldest forms of the kind known to us were not much bigger than foxes. The facts just given form, however, but a very small part of our knowledge regarding the ancestry of Horses. It will be shown in a later section that there is good reason for believing that not only Horses, but all hoofed Mammals, together with Conies and Elephants, are descended from small swamp-inhabiting forms, which were plantigrade, and possessed the full complement of five digits on both fore- and hind-feet.

A few words are here necessary on the structure of the Horse's hoof, which is merely an exaggeration, so to speak, of

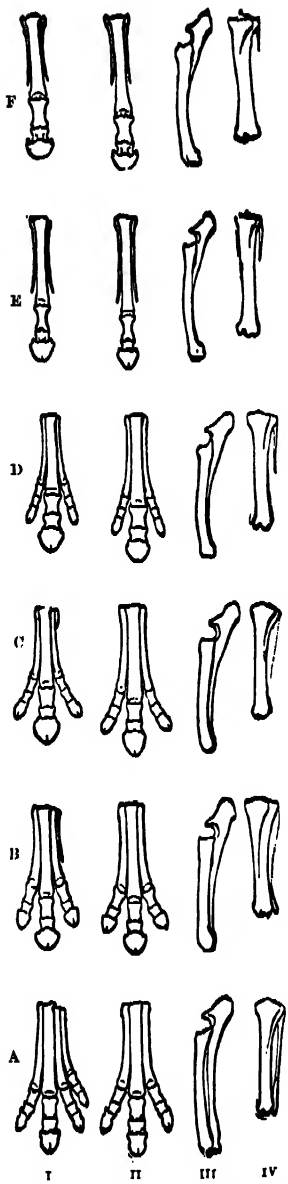
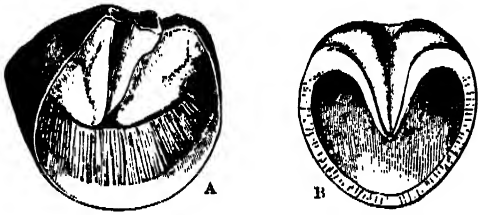


Fig. 694.—Evolution of Limbs of Horse

I, Fore-foot; II, hind-foot; III, fore-arm; IV, lower leg. A–E, Bones of extinct horse-like animals, Orohippus, Mesohippus, Miohippus (Anchitherium), Protohippus (Hipparion), Pliohippus. F, Bones of Horse (Equus). Read from below upwards (*i.e.* in order of geological age), and note gradual reduction in number of digits, and diminution of size of one forearm bone (ulna), and one lower leg bone (fibula).

what in ourselves we should call a finger-nail or a toe-nail. It constitutes a sort of horny box (fig. 695) supported by the expanded end-bone of the digit, and is composed of a complicated series of layers, so arranged as to combine great firmness with considerable elasticity. The latter property is of importance, as it mitigates the severe shocks to which the hoof is necessarily exposed. Although the locomotor organs of Horses were no doubt evolved with reference to swift progression on even and fairly firm ground, this was far more yielding in character than ordinary roads constructed by human agency. Hence arises the necessity for shoeing horses which constantly traverse these, as, if left unshod, the hoofs would wear away much too quickly. Really scientific farriery involves a thorough knowledge of the structure of the feet, and this important art, as practised in our own country, leaves much to be desired.



. 695.—Horse's Hoof. A, Interior; B, under surface

Paces of the Horse.—The five chief kinds of pace which have been subjected to careful analysis are: the walk, the amble, the low trot, the ordinary trot, and the gallop. Of these the first three are varieties of walking, and the last two forms of running.

The ordinary *walk* of a Horse is effected in the same diagonal way already described for the Dog (see p. 136), the sequence, commencing with the right fore-foot, being—right fore, left hind, left fore, right hind. A regular series of equal sounds results, produced by the four successive hoof-falls. In both *amble* and *trot* two feet are placed on the ground simultaneously. The former is an artificial pace, which has to be taught to the animal. In it the two limbs of the same side move together, and two men walking one behind the other and keeping step would represent the succession, which would be—right fore and right hind together, left fore and left hind together. The sounds resulting would of course be a regular succession of double hoof-falls. What is known as the *low trot* agrees with this in so far that two feet are placed on the ground at the same time, but they are diagonally opposite one another, the sequence being—right fore and left hind together, left fore and right hind together.

In the *ordinary trot* the body entirely leaves the ground for a very short time between the successive impacts of the feet, and this kind of pace may therefore be considered a kind of running. The *gallop* is a more rapid run, and is distinguished from the trot by the irregularity of the sound produced, which is familiar to everyone, and is due to the fact that there is neither a regular succession of single hoof-falls, as in the walk, nor of double hoof-falls, as in the amble and trot, but a mixture of the two. Several kinds of gallop can be distinguished, which differ a good deal from one another. A simple variety is the one known as the gallop in three-time, because three successive sounds can be distinguished between one moment of suspension in the air and that next following. First comes a single hoof-fall, then a double one, and then a single one again. It appears that after suspension in the air the feet come down as follows—left hind, left fore and right hind together, right fore. Or it may be—right hind, right fore and left hind together, left fore. The first sequence applies to some horses, and the second to others. The instantaneous photographs represented in fig. 696 give two phases in such a gallop. Above is shown the horse resting on one fore-foot preparatory to leaving the ground altogether; below, the horse is seen actually suspended in the air. The times at which the hoofs reach and leave the ground are so related in one variety of this pace that the animal successively rests on the following number of legs: 1, 3, 2, 3, 1. In the first sequence given above these would be—left hind; left hind, right hind, left fore; right hind, left fore; right hind, left fore, right fore; right fore. In another variety of the three-time gallop the body alternately rests on one foot and on three feet.

Fig 696. - Instantaneous Photographs of Horse Galloping. See text

What is known as the *full gallop*, the successive phases of which are given in fig. 697, is said to be in four-time, because four successive impacts are given by the hoofs, as follows (in

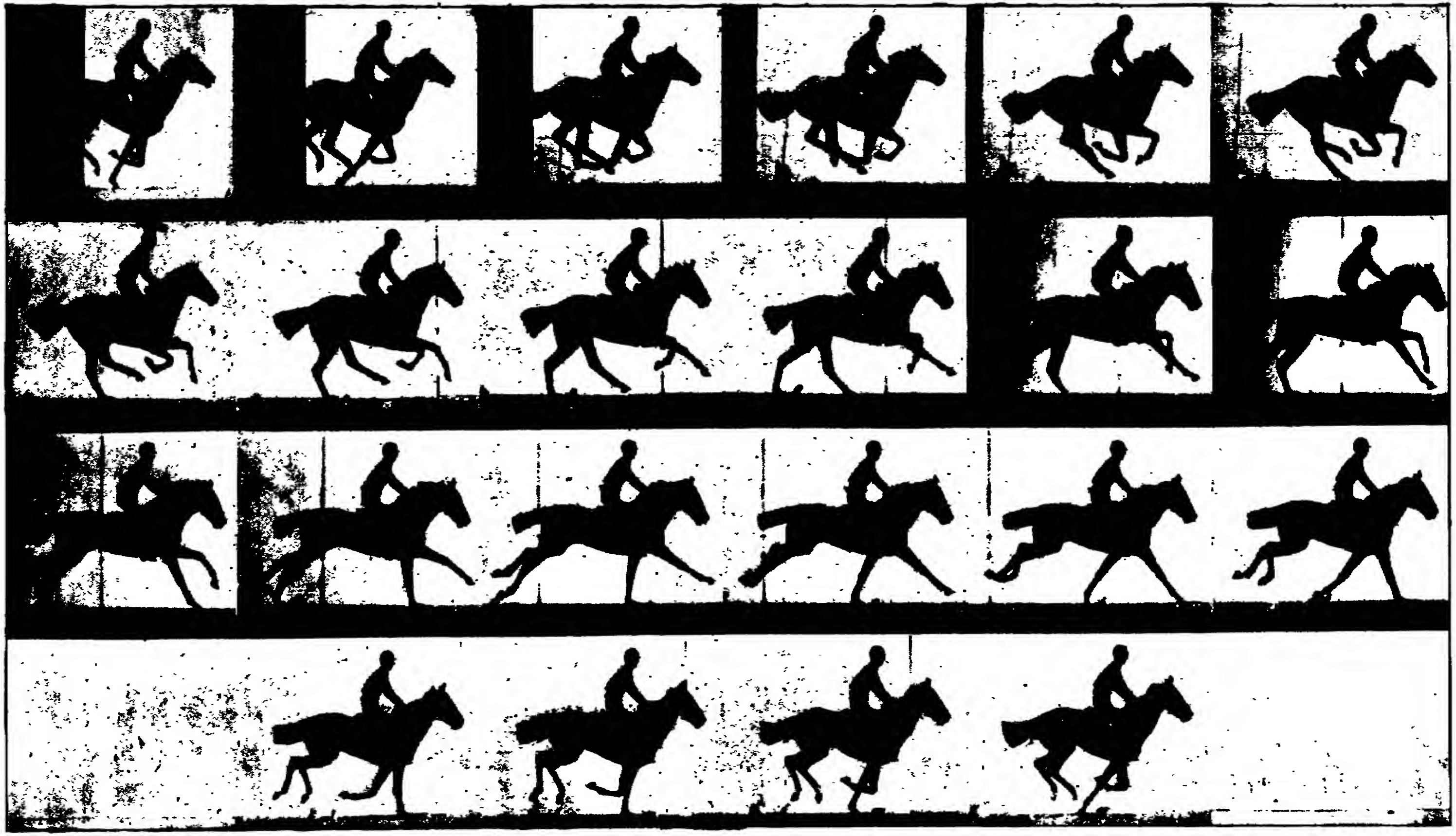


Fig. 697.—Series of Instantaneous Photographs of a Horse Galloping. Read from left to right beginning with uppermost row. See text

one of the two sequences)—left hind, right hind, left fore, right fore. It will be observed that the body is sometimes supported on one foot, at other times on two.

Mechanical devices have been invented, by which the hoofs can be made to register the exact times at which they reach and leave the ground. Diagrams of such automatic registration for walk, low trot, and one variety of three-time gallop, is given in fig. 698. Each foot is represented by a rectangle, the length of which is proportionate to the time the hoof rests on the ground. Perpendicular lines drawn across the diagrams show the number of feet (if any) resting on the ground in different phases of the movement.

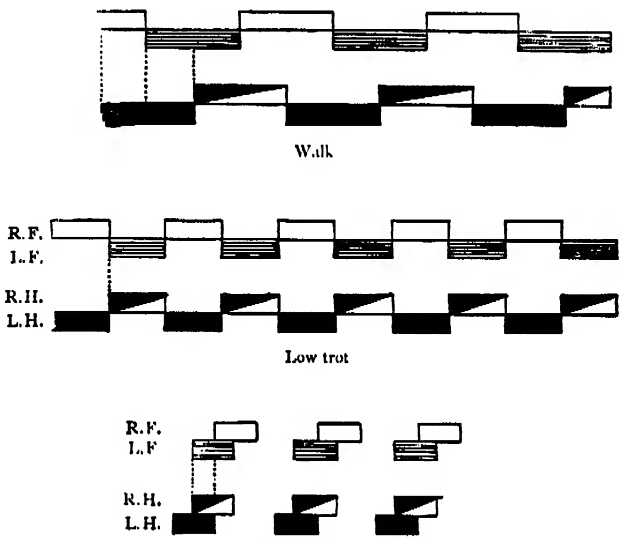


Fig. 698.—Paces of Horse Mechanically Registered
R.F., Right fore-foot; L.F., left fore-foot; R.H., right hind-foot; L.H., left hind-foot. See text.

Even-toed Ungulates (Artiodactyla).—As among the Odd-toed Ungulates, so also in this group, it is easy to pick out a series of forms which illustrate increasing specialization, resulting from adaptation to swift progression on firm surfaces. But the same end is here attained in a somewhat different manner, for *two* digits, the 3rd and 4th, become dominant, the axis of symmetry of the limb running between them, while in Odd-toed Ungulates only *one* digit, the 3rd, continues to increase in importance, and the axis of symmetry runs through it. The difference between the two types is clearly brought out in fig. 701.

These Even-toed or "cloven-footed" Ungulates include non-ruminating forms (Hippopotami and Swine), which are comparatively simple in structure, and far more numerous ruminants

or "cud-chewers" (Cattle, Deer, &c.), some of which are as specialized as Horses, which they rival or even excel in speed.

The Hippopotamus is a creature of such vast bulk, and the ground upon which it walks when it comes out of the water is so soft, that we should naturally expect the feet to present a large surface of support, to be of spreading character, and to exhibit but little, if any, reduction in the number of digits. The structure of this animal fully justifies such expectations. The limbs are short and strong, with wrists and ankles raised but little from the ground, for palm- and instep-regions are both short. It is true that the innermost digits (thumbs and great toes) have been lost, but the four remaining in each foot are of about the same size, and terminate in pointed hoofs on which the body rests. The reason for absence of much reduction in the extremities is put very graphically by Oscar Schmidt (in *The Mammalia*), where, speaking of the primitive ancestors of hoofed Mammals, he says that these ". . . had to dwell principally in waters and on marshy ground. Their descendants adapted themselves gradually to life on dry ground, and this is connected with the advantageous reduction of the toes. The Hippopotamus . . . has taken an opposite course; from being an animal that liked the marshy soil of the primeval forests, it has become almost an aquatic creature, and accordingly has preserved the completeness of hand and foot, the four toes almost fully developed. . . . A one-toed hippopotamus in the natural course of development is an impossibility. The gradual reduction of the toes, as already said, can be connected only with the drying up of marshy lands. And if, by some extravagant flight of the imagination, we could conceive the existence of a one-toed leviathan, the very fact of its possessing a one-toed foot would be the cause of its speedy extinction."

It appears that the Hippopotamus can make its way very quickly along the bed of its native river, the body being buoyed up by the water to a convenient extent, and it can also climb with facility up mud-banks and on to shoals, the pointed hoofs of the spreading feet giving a sufficiently good hold for the purpose.

Swine and their immediate allies are comparatively short-limbed, and though possessed of considerable powers of speed, are in most cases essentially marsh-loving animals, so that feet

capable of a certain amount of spreading are a necessary endowment. And we find accordingly that the extremities represent a sort of compromise between adaptations necessary for speed and arrangements suitable for progression on yielding surfaces. The bones of the forearm (radius and ulna) and lower leg (tibia and fibula) are both complete, palm-region and instep-region are of moderate length, and one digit (thumb or great toe) has been lost in each foot. Of the four digits which remain, two (third and

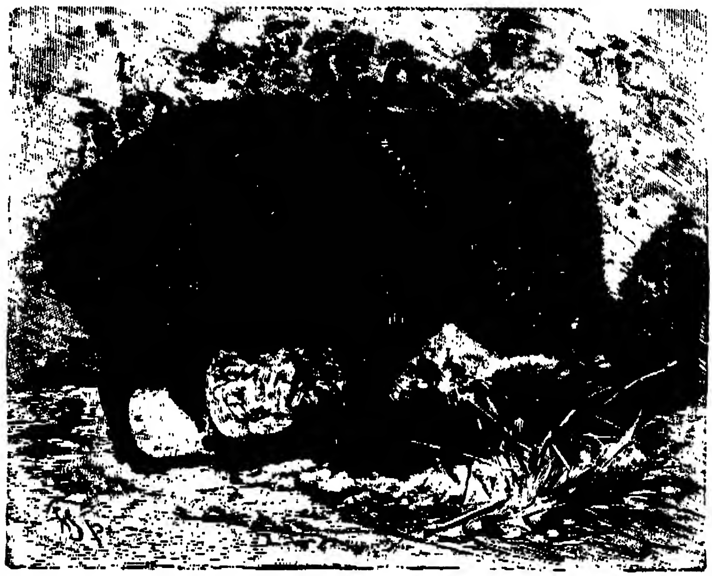


Fig. 699.—Collared Peccary (*Dicotyles torquatus*)

fourth) are large, and their ends are encased in hoofs upon which the animal walks, while the other two (second and fifth) are small, and possess little hoofs which do not touch the ground when this is firm enough to fully sustain the animal's weight. But when a pig traverses marshy ground, the two large toes separate to some extent and give an increased surface; while if, even in spite of this, the feet sink in to some extent, the two small toes act as "stops", which more or less check further sinking.

It is very interesting to note that the little, slender-legged Peccaries (fig. 699) of South America, animals which are included in the Pig family, are more specialized as regards the structure of the feet, for the two central palm-bones of the fore-limb are fused together into a "cannon-bone", which is also the case with the two central instep-bones of the hind-limb. [The structure so

called in a horse is only *one* large bone (see p. 142).] And besides this, the hind-feet of a Peccary have lost the outermost (fifth) toes. The extremities, in short, are better suited for progression on firm surfaces than is the case in ordinary pigs, and, as we might expect, Peccaries are not such distinctively marsh-loving creatures. Nor is it surprising to find that they can run more quickly than pigs.

Ruminants (fig. 700) present a series of cases in which the kind of specialization seen in swine is carried to an increasingly greater extent. The two chief toes (third and fourth) become more and more dominant, and the two palm-bones or instep-bones which belong to them fuse together into a "cannon-bone", as in the Peccaries. At the same time the two side-toes (second and fifth) dwindle and ultimately disappear. As Vogt says (in *The Mammalia*): "There is thus a series of developments by which the two lateral digits get more and more reduced, and this series is the continuation of that which was presented by the preceding group (*i.e.* Hippopotami and Swine). At the same time the limbs become more slender and longer as the fleetness of the animal increases. Among the Ruminants we meet with runners which surpass all other known Mammals in point of speed." This acquisition of great powers of locomotion is undoubtedly in direct relation to the habit of ruminating or cud-chewing (see vol. ii, p. 169). For animals of this kind are able to hurriedly fill their paunches with food, after which they can rapidly seek places of safety on higher ground. This commonly necessitates a good deal of clambering, for which a spreading two-toed foot is much better suited than a one-toed foot like that of a horse (compare p. 140).

By far the least specialized Ruminants are the little Chevrotains (*Tragulidæ*) of South-east Asia and West Africa, which give us a good idea of the structure and habits of the remote ancestors from which all the even-toed Ungulates are descended. This is particularly true of the Water Chevrotain (*Dorcatherium*) from the latter region. The feet (fig. 701) are much like those of a pig, except that the two side-toes are relatively smaller. The two large palm-bones of the fore-foot have not fused into a cannon-bone (fig. 701), but the two large instep-bones of the hind-foot have, on the contrary, more or less united together. The Asiatic Chevrotain or Kanchil (*Tragulus*) is rather more

DORCAS GAZELLES (*Gazella Dorcas*)

Few animals are better able to escape from enemies by sheer speed than Antelopes, and among these the slender little Gazelles are particularly well endowed as regards running powers. The plate represents a herd of Dorcas Gazelles in rapid movement, and it will be noted that the attitudes assumed can scarcely be termed graceful. This particular species is common in the desert regions of North Africa and South-west Asia, and elegantly curved horns are present in both sexes, although those of the female are relatively slender. Gazelles frequently leap high into the air whilst running. As in desert animals generally, the colour closely matches the surroundings, thus promoting inconspicuousness. In the present instance this may be interpreted as a case of protective coloration.

DORCAS GAZELLES (GAZELLA DORCAS)

Fig. 700.—Ruminants.—1, Giraffe (*Giraffa camelopardalis*); 2, Arabian Camel (*Camelus dromedarius*); 3, Fallow-Deer (*Cervus dama*); 4, Prongbuck (*Antilocapra Americana*); 5, Alpine Ibex (*Capra ibex*); 6, Musk-Deer (*Moschus moschiferus*).

specialized, for cannon-bones are present in both pairs of limbs. In Chevrotains, as in all other Ruminants, the ulna and fibula are reduced, but the latter is complete though slender. In the remaining cud-chewers it is only represented by a little nodule (malleolar bone) just above the ankle-bones.

Deer (*Cervidæ*) are much larger and swifter animals than Chevrotains, and, like the rest of the Ruminants, live on firmer ground, to which their speed is an adaptation. The outer toes are reduced to insignificant vestiges, which project, however, at the exterior.

A very interesting case of adaptation to progression on a yielding surface is presented by the Reindeer (*Rangifer tarandus*), which may be said to possess "snow-feet", that can be so spread out as to give an increased walking surface, much as is the case with the marsh-feet of a pig or chevrotain. The hoofs of the two large toes are of considerable size and strongly curved, with concave sides facing one another, and convex outer edges. When pressed down on the snow they separate widely, so that the fairly large hoofs of the outer toes touch the ground and help to support the weight of the body, which is very considerable. A less-marked arrangement of similar kind is found in the Elk or Moose (*Alces machlis*), which is also a northern form, though it does not range into treeless wastes as does the reindeer.

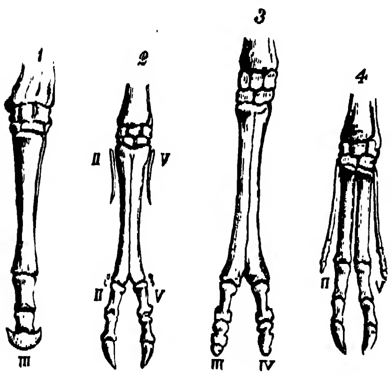


Fig. 701.—Bones of Fore-feet of Hoofed Animals
1, Horse; 2, Sheep; 3, Camel; 4, Water-Chevrotain (*Dorcatherium*). II–V, 2nd to 5th digits.

The Hollow-horned Ruminants (*Cavicornia*), including Antelopes, Cattle, Sheep, and Goats, present a further stage in the reduction of the side-toes, which are represented by traces of their supporting bones (fig. 701), and commonly also by little external projections bearing small accessory hoofs.

The Camel Family (*Tylopoda*), which includes the Camels of the Old World and the Llamas of the New, is characterized by the entire loss of the two small outer digits (second and fifth), which persist more or less in the Even-toed Ungulates so far considered. The two bones which have united together to form

the cannon-bone in the Camel diverge below (fig. 701), an arrangement which gives a large surface of attachment for a firm pad on the under side of the foot. This is in relation to the yielding nature of the sand upon which the animal walks, for these pads greatly increase the surface of contact with the sand, and thus help to prevent the feet from sinking into it, at the same time preventing them from becoming unduly heated. The adaptation is remarkably like that found in the African Ostrich (see p. 130), where, however, one of the two toes present is very much larger than the other, and the foot is well cleft, while that of the Camel is only slightly so.

It is further interesting to note that the Camel is one of the very few animals of which the natural walk is an amble (see p. 144), other cases being the Giraffe and the Elephant. All three are more or less heavy creatures which habitually traverse yielding surfaces, and very probably their ambling may be explained by reference to these facts. For in this particular pace two feet are brought forward and set down together, thus doubling the surface of contact and halving the weight of the body between them, thus greatly reducing the tendency to sink into the ground.

Two wild species of camel-like animals, the Guanaco (*Lama guanacus*) and Vicunia (*L. vicunia*), are native to South America. Their structure is essentially like that of camels, but the body is smaller, the limbs more slender. Each toe of the more deeply-cleft foot bears a pad. Both animals are active mountain-climbers, especially the Vicunia, and the differences between their feet and those of camels are adaptations to this different way of life. The larger Guanaco, however, is also found in the plains, where it is associated with the South American Ostriches (*Rhea*), just as the Camel and African Ostrich (*Struthio*) are found together under similar conditions in the Old World.

Of all existing Even-toed Ungulates the Giraffes (*Giraffidæ*) are the most specialized (fig. 700). There is not the same disproportion between the length of fore- and hind-limbs as in other Ungulates, and the region between wrist or ankle and hand or foot is remarkably elongated. Both outer digits (second and fifth) have been lost entirely, and the two which still remain (third and fourth) possess very large hoofs. As already stated, the walking pace is an amble.

Until quite recently the Giraffe held a very isolated position among existing Ungulates, but the gap has partly been filled up by the discovery of what may be called a short-necked giraffe in Central Africa. This animal, the Okapi (*Okapia Johnstoni*), resembles its larger congener in many respects, but little is so far known regarding its habits.

FLESH-EATING MAMMALS (*Carnivora*) AS WALKERS AND RUNNERS.—Sufficient is known about extinct fossil Mammals to make it certain that the remote ancestors of the dogs, bears, lions, &c., of to-day were small marsh-inhabiting creatures, which had the full number of digits and walked upon the palms of their hands and soles of their feet. From animals of this sort Carnivores and Ungulates have both sprung (see p. 143). As we go back in time the characters of the two orders are less and less well marked, till we ultimately make the acquaintance of forms which cannot well be placed in either order, but give us a good idea of what the common ancestors of the two groups were like.

Existing Carnivores present us with a long series of stages in the evolution of efficient organs of locomotion, though even the most specialized do not parallel such animals as horses and giraffes in the matter of reduction of digits and lengthening of palm and instep regions. This is intelligible when we consider the habits of typical beasts of prey. Those of the dog kind excepted, there are but few of them which rely upon sheer speed to secure their prey, and the members of the highly-modified Cat family adopt more stealthy tactics, in the final stage of which a sudden and powerful spring is the most important matter. Besides this, the limbs have other work to do besides locomotion, and the necessity for lateral movement has checked specialization on ungulate lines. Effective seizing of prey, for example, is incompatible with great reduction in the number and mobility of digits.

The Dog has already been described at some length as an illustration of some of the main features of Mammalian locomotion, and the correlated characters presented by the bodily structure (see p. 132). It is typically digitigrade, *i.e.* walks upon its digits, and the wrists and ankles are well lifted off the ground (fig. 686, p. 133); but these regions are not elongated to the same extent as in many of the Hoofed Mammals, nor

is there any fusion of the palm- or instep-bones. It is further to be remarked, that in the Dog and other digitigrade Carnivores the weight of the body is not borne upon the extreme

Fig 702.—Brown Bears (*Ursus arctos*)

tips of the toes, as in, say, a horse, but upon elastic pads borne upon the under sides of the paws (fig. 707). The three joints of each digit are bent in a peculiar way, one result of which is to keep the claws off the ground, and in members of the Cat family these are even drawn back into special sheaths when not actually in use.

Fig. 703.—Under Surfaces of a Bear's Paws

The *Large Bears* (Ursidæ) (fig. 702) are not modified like dogs, &c., in relation to rapid progression, for they are typically plantigrade, walking on palms and soles. Both fore- and hind-feet possess the full number of five digits. It is a familiar fact that Bears are able to progress for some distance upon their hind-limbs only, especially when attacked by human beings. The broad soles of the hind-feet (fig. 703) render such a mode of progression comparatively easy to them.

The paws of the Polar Bear (*Ursus maritimus*) are of very great size, and their under surfaces are hair-clad. These features

are not improbably related to the necessity for constantly traversing snow and the slippery surface of ice.

The *Weasel and Badger Family* (Mustelidæ) is one of great antiquity, and all five digits are present in fore- and hind-feet. There are considerable differences between the various members of the family as regards the way in which the feet are placed on the ground. A Common Badger (*Meles taxus*), for instance, is plantigrade, while the smaller creatures known as Martens, Weasels, &c., raise the wrists and ankles more or less off the

Fig. 704.- Sable (*Mustela zi*

ground, and are therefore to some extent digitigrade. But as some part of the palm and instep regions touch the ground as well as the digits themselves, we have a sort of intermediate stage between plantigrade and digitigrade conditions. This *semi-plantigrade* arrangement, as it is usually called, is well seen in the Sable (*Mustela zibellina*, fig. 704), and is particularly interesting because it indicates the way in which a more specialized way of walking has been gradually evolved from a less specialized, constituting in this respect a sort of half-way house between what is found in a bear or badger on the one hand, and a lion or cat on the other.

The small Carnivores known as *Viverrines* (Viverridæ), including Mangoustis and Civets, constitute a group which is in many ways more primitive than the one last mentioned. Mangoustis,

of which the best-known types are the Ichneumons, are semi-plantigrade, while the Civets have gone a stage further in specialization, for palm and instep regions are well lifted off the ground, so that the term digitigrade is here applicable. This is very well seen in the African Civet-Cat (*Viverra civetta*, fig. 705). As regards the mode of progression, Civets are therefore more highly modified than Mangoustis; but in spite of this the full number of five digits are present both on

Fig. 705.—African Civet-Cat (*Viverra civetta*)

fore- and hind-feet, while in Mangoustis and their immediate allies the first digits (thumbs and great toes) are reduced in size, or in some cases even absent altogether.

The members of the *Cat* family (Felidæ) are the most highly specialized of all Flesh-eating Mammals, and are completely digitigrade, as may be seen in the Common Cat (*Felis domesticus*, fig. 706). The weight of the body rests upon elastic pads on the under sides of the paws (fig. 707). Five digits are present on the fore-paw, but the first one (great toe) has been lost in the hind-paw.

Probably the fleetest of all existing Carnivores, at least for short distances, are the Hunting Leopards, of which the Indian Cheetah (*Cynailurus jubatus*, see vol. ii, p. 11) is a well-known example. In these forms the legs are unusually long and slender,

and the claws cannot be drawn back into special sheaths, as in the other members of the Cat family.

Monkeys and Men (*Primates*).—It would appear that the evolution of the members of this order has been related in the

Fig. 706.—Common Cat (*Felis domesticus*)

first instance to the climbing habit, and to the use of the limbs for various other purposes involving complex movements. In accordance with this we find the collar-bones well developed, as in all cases where the arms are capable of a large amount of lateral action. Both bones of the forearm (radius and ulna) and lower leg (tibia and fibula) are well developed, and so arranged in the former as to permit of twisting on the long axis, the radius, which carries the hand, rolling over the ulna as it were (see vol. i, p. 30). And in all cases the full number of digits is present, though it occasionally happens that the thumb is reduced in size.

Fig. 707.—Upper and under Sides of a Cat's Fore-paw
The claws are protruded in the former and the "pads" are seen in the latter.

When an ordinary Monkey has occasion to walk on the ground, it does so on all-fours, in plantigrade fashion; and this is also the case in Baboons, which are in the main ground animals (fig. 708).

The higher or Anthropoid Apes, though all expert climbers,

present a series of adaptations to walking on the hinder limbs only, which lead up to the very perfect structural arrangements by which Man is eminently fitted for progression of this kind.

Bipedal locomotion in Primates is entirely different from what has already been described for Birds (see p. 125). In the latter the legs are set on far forwards, the body being as it were slung

Fig. 708. Black Baboon of Celebes (*Cynopithecus niger*)

between them, with its long axis oblique. Birds are also digitigrade in a marked degree. In the higher Apes and Man, on the contrary, there is an increasing tendency for the pelvis to form a strong bony basin, built on the principle of the arch, and adapted to support the weight of the trunk, of which the long axis becomes vertical in the last stage of the evolutionary series. At the same time the tail has been reduced to an insignificant vestige. It must further be noted that the legs become relatively longer as the power of walking on them alone is gradually improved,

and the feet more suited to bear the weight of the body. At the same time the arms become relatively shorter.

Higher Apes (Anthropomorpha, fig. 709).—The Gibbons of Asia are comparatively small creatures of eminently arboreal habit. Their arms are of extraordinary length, more than sufficient to enable them to touch the ground when the erect position

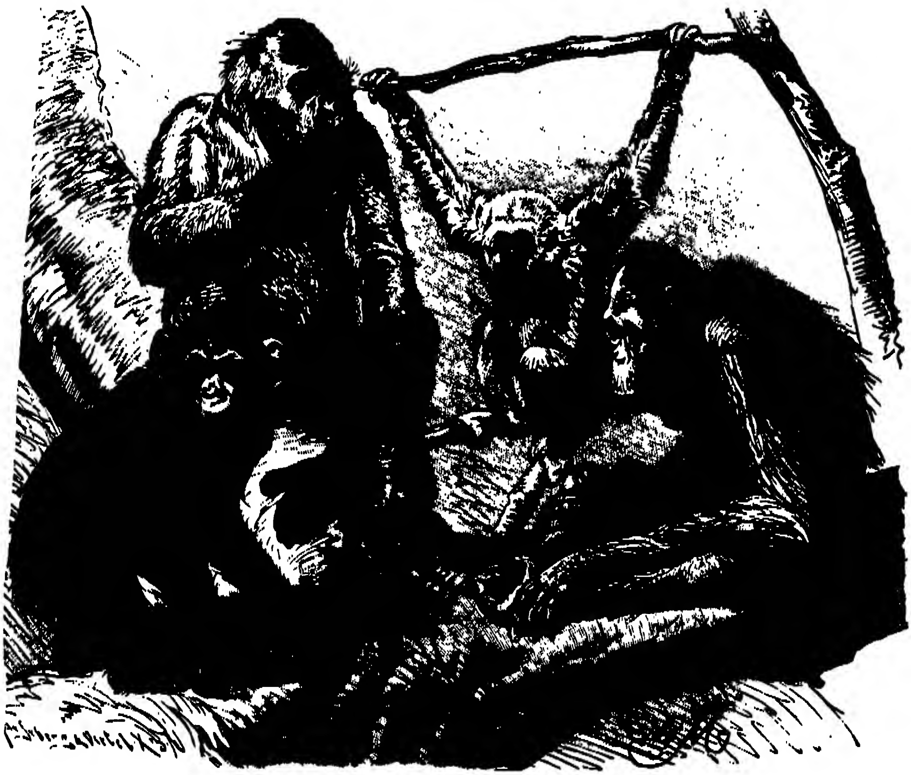


Fig. 709.—Higher or Anthropoid Apes

1, Gorilla (*Gorilla Savagei*); 2, Chimpanzee (*Anthropopithecus niger*); 3, Silver Gibbon (*Hylobates leuciscus*); 4, Orang-utan (*Simia satyrus*).

is assumed. Regarding their mode of walking, Vogt (in *The Mammalia*) speaks as follows:—"They [*i.e.* the arms] are so long that the Gibbons but seldom make use of them in walking on the ground, which indeed they touch only on exceptional occasions when living in freedom. They then waddle along upright, with their great toes widely spread out, with uplifted arms spread out sidewards as a balancing-rod, the long hands hanging down like goose wing-dusters, the head hanging a little forwards, and the back bent like a fiddle-bow." It is asserted

by some authorities that Gibbons walk better on hind-limbs alone than the other higher apes.

The Orang-utan, Chimpanzee, and Gorilla mostly walk on all-fours, and usually bend their fingers so that the backs of these touch the ground. But on occasion all three are able to progress as bipeds. The Orang-Utan (*Simia satyrus*) is a thoroughly arboreal form, and its arms are only a little shorter than those of the Gibbons. In the erect posture the knuckles can be placed on the ground, and thus the animal is able to steady itself when walking on the hind-legs, as it sometimes does. The Chimpanzee (*Anthropopithecus niger*) and Gorilla (*Gorilla Savagei*), though good climbers, live on the ground to a much larger extent than their Asiatic cousins. Both are able to walk on the hind-legs with a rather tottering gait, and under these circumstances the fore-limbs give no help, for they are considerably shorter than in the Orang. But even in the Gorilla, which approaches most nearly to Man in its proportions, the legs are comparatively short, while the arms hang down below the knees.

Walking and Running of Man.—The structure of the human skeleton, as adapted to the erect attitude, has already

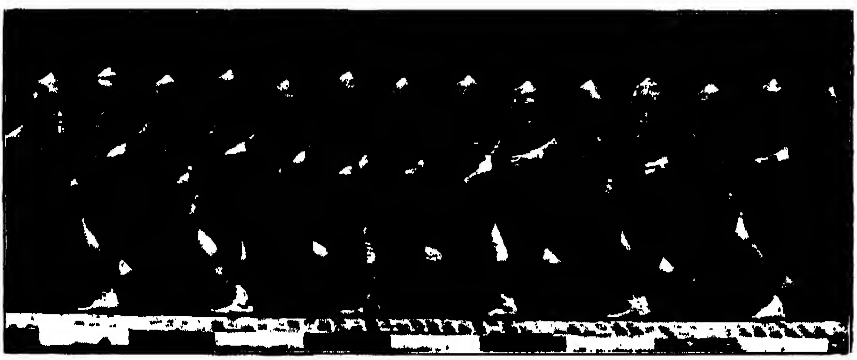


Fig. 710.—Series of photographs of a Man walking. Read from right to left

been considered at some length (see vol. i, pp. 25-32). But the adaptation is by no means perfect, for after all, human beings are but highly-specialized quadrupeds, and the habitually upright position of the body is related to a number of complaints, chiefly as the result of undue pressure upon such internal organs as are situated in the lower part of the trunk.

Some of the successive stages of human walking are represented in fig. 710, taken from a series of photographs. By

examining this from right to left a number of points will be observed. It is clear that the forward impulse, resulting from the backward push of each leg in turn against the ground, largely depends upon alternate bending and straightening of the limbs. Some little assistance is also given by the swinging of the arms, which move one after the other at the same time as the opposite leg. The purely plantigrade nature of this typical "heel-and-toe" work is also apparent, and it will be seen that the heel reaches the ground first. It will further be noted that the body moves in a wave-like curve, a fact which is best realized by following the successive positions of the head.

When a Man runs in the most advantageous way he lifts his heels from the ground and becomes a digitigrade animal for the time being. The legs now in turn bend and straighten with such vigour that the backward pushes they give project the body entirely off the ground at each stride. And as a matter of course the rate of progression is proportionate to the force with which the bending and straightening of the legs are effected.

WALKING OF JOINTED-LIMBED INVERTEBRATES (ARTHROPODA)

The problems presented by the locomotion of backboned animals are by no means easy to solve, but the study of Jointed-Limbed Invertebrates (*Arthropoda*) presents even greater difficulties. This is due to the great complexity of their structure, the number of their limbs, and the fact that each limb is made up of more numerous sections than is the case with the corresponding organs of Amphibians, Reptiles, and Mammals. And the comparatively small size of Arthropods of course renders investigation more difficult. A good deal of attention has been paid to the subject of late years, but it is beyond the scope of a work like this to do more than give some of the more elementary facts which have been determined.

The mechanical arrangements by which walking is effected in Arthropods are very different from those characteristic of Vertebrates. The bodies of the latter are supported by a complex internal skeleton, of which the parts are so jointed together as to permit of the necessary movements. The equally or perhaps more complex muscular system largely consists of fleshy bands

(muscles) attached to the bones which make up the skeleton. But in an Arthropod, such as a lobster or insect, the skeleton is external, consisting of a hard layer covering the skin. Where movement is required, thin flexible places are found in this firm covering, and at such spots the thicker parts of the skeleton are provided with projections and sockets which so fit into one another as to constitute efficient joints of various kind, and comparable to the ball-and-socket joints, hinge-joints, &c., possessed by the internal skeleton of backboned animals. The numerous muscles which effect movement are of necessity attached to the inner surface of the hard covering of the body, as will be understood by reference to fig. 711, which represents diagrammatically the leg of an insect.

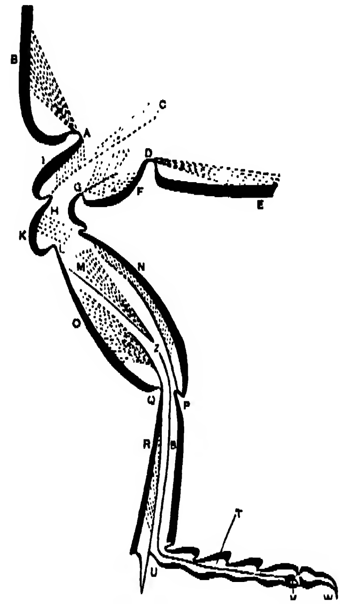


Fig. 711.—Diagram of an Insect's Leg in longitudinal section

The black outline represents the hard skeleton: the muscles are dotted and their tendons are drawn as thin unbroken lines. B E, Body; I F, hip (coxa); K, trochanter; O N, thigh (femur); R, shin (tibia); U V W, foot (tarsus) with end-claw. B A, C, K D, Muscles which move leg on body; K L, muscle which draws thigh inwards; F G, N P, muscles which straighten out the leg; I H, O Q, R U, M Z (with long tendon Z S T V), muscles which bend the parts of the leg upon one another.

There can be little doubt that Arthropods are descended from creatures resembling Bristle-Worms in many respects. We have seen (p. 98) that a typical worm of this kind is made up of a considerable number of rings or segments, each possessing a pair of hollow, unjointed foot-stumps, by the successive action of which creeping is effected in an undulating manner. As already mentioned (p. 101), the primitive air-breathing form Peripatus resembles a bristle-worm in certain particulars, as, for example, the structure of its many legs, which are much like modified foot-stumps, and are used in the same manner. It will now be convenient to consider the methods of walking practised by Centipedes and Millipedes (*Myriapoda*); Insects (*Insecta*); Scorpions, Spiders, &c. (*Arachnida*); and Crustaceans (*Crustacea*).

Centipedes and Millipedes (*Myriapoda*) as Walkers.—The creatures of this class present an advance upon Peripatus in the structure of their numerous legs, which are solid and dis-

tinctly jointed, as in all the other Arthropods to be considered. Myriapods walk on the claws with which their limbs are furnished, thus reminding us of the hoof-walkers among Mammals (see p. 137).

The vegetarian *Millipedes* are comparatively sluggish, and most of the segments of the body each bear two pairs of feeble legs, the bases of which are close together on the under side of the body. It is obvious that weak and numerous limbs attached in this way are not adapted for rapid locomotion. The two members of a pair are moved together, and a sort of wave of movement passes along the numerous legs during walking, as is usually the case in many-limbed animals. A very graphic account of this sort of movement is quoted by Heathcote (in *The Cambridge Natural History*) from an old and curiously-named book (*An Essay towards a Natural History of Serpents.* Charles Owen, D.D., London, 1742). The passage runs as follows:—"The Ambua, so the natives of Brazil call the Millipedes and the Centipedes, are serpents. These reptiles of thousand legs bend as they crawl along, and are reckoned very poisonous. In these Multipedes the mechanism of the body is very curious; in their going it is observable that on each side of their bodies each leg has its motion, one regularly after another, so that their legs, being numerous, form a kind of undulation, and thereby communicate to the body a swifter progression than one could imagine where so many short feet are to take so many short steps, that follow one another rolling on like the waves of the sea." The name Millipede, *i.e.* thousand-legs, is not very fortunate, for in average cases 100 pairs may be considered a liberal estimate, and in some short-bodied forms the number may sink as low as 13 pairs.

The carnivorous *Centipedes* are much more active than their vegetarian cousins, in accordance with which their legs are longer and stouter, and their bases farther apart. Most of the segments bear one pair each, and the two limbs of a pair move alternately and not together, an arrangement which would seem to favour speed. The body, being flattened from above downwards, is better suited for rapid progression than the almost cylindrical body of a Millipede. Here again the popular name Centipede, meaning hundred-legs, is not very appropriate, for some species are much elongated and may possess as many as 173 pairs of

legs, while one form, common in our gardens (*Lithobius*, see vol. ii, p. 132), is quite short and has but 15 pairs. It is a curious fact that the number of pairs is always odd.

Typical Centipedes can move backwards as well as forwards, and the short forms progress more rapidly than the long ones, as might be expected. The Shield-bearing Centipede (*Scutigera*, vol. ii, p. 436), which differs so much from other forms as to be considered the type of a distinct order, is quite remarkable for its speed, and its legs, of which only 9 pairs are present, are remarkably long and stilt-like (fig. 712).

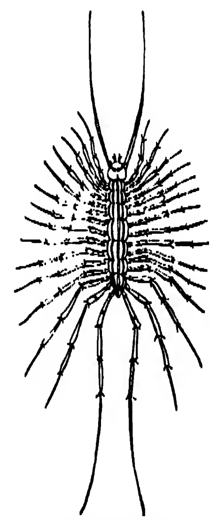


Fig. 712.—Shield-bearing Centipede (*Scutigera*

Insects (*Insecta*) as Walkers.—Average insects possess but three pairs of legs, which are well developed, and attached to the central part or thorax of the comparatively short body. We find, however, that during development a number of abdominal legs begin to make their appearance, and may sometimes be retained as little stumps on the under side of the body in the adults of primitive wingless forms, though as a rule they disappear completely. From these and many other facts the conclusion has been reached that the remote ancestors of insects possessed more than three pairs of legs, and were probably not unlike short centipedes. And there can be no doubt that insects have gradually become compacter in form, while at the same time the number of legs has undergone reduction, in the interests of effective walking and climbing, among other things.

Elaborate investigations have been made upon the walk of Insects, a subject which is as interesting as it is complicated, though the simpler results are quite easy to understand. The elasticity of the legs appears to be a work-saving contrivance, for after a movement has been made this helps to bring them back to the position naturally assumed in a state of rest, when they are ready for a second effort. Just as if, say, a human limb, after having been bent by muscular action, could again straighten itself by elastic recoil without the use of muscles. On this point Packard, when summarizing (in his *Text-Book of Entomology*) the work of Graber, the most eminent authority on this particular subject, says: "Considering the respective positions of

the individual levers of the leg and the nature of the materials of which they are made, the legs of insects may be likened, as Graber states, to elastic bows, which, when pressed down together from above, their own indwelling elasticity is able to raise them again and thus keep the body upright. This is very plainly shown in certain stilt-legged bark-beetles, in which, as in a rubber doll, as soon as the body is pressed down on the ground, the organs of motion extend again without the intervention of muscles; indeed, this experiment succeeds even with dead, but not yet wholly stiff, insects."

It further appears that most adult insects are *plantigrade*, walking on the whole of the surfaces of the feet or tarsi in which the limbs terminate, though, of course, these regions are not strictly comparable to the feet of backboned animals. The tips of the legs are provided with hooks which hold firmly to the underlying surface, unless this is very smooth. Hence the ease with which insects walk up inclined planes or upon narrow twigs. In the latter case the large feelers (antennæ) which certain forms possess appear to be used as balancers, playing the same part in this respect as the tail of the cat and many other Mammals.

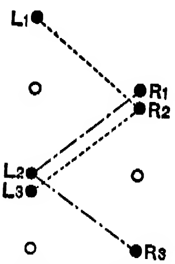


Fig. 713.—Diagram Plan of a Phase in an Insect's Walk

L1, L2, L3, First, second, and third legs of left side; R1, R2, R3, first, second, and third legs of right side. The legs which work together are connected by dotted lines. L1, R2, and L3 have just stepped forwards together (from positions indicated by unshaded circles).

As might be expected, the legs of an insect are moved diagonally, presenting a modification of the principle we have found to be usually applicable to quadrupeds (see p. 121). In considering their action it will be convenient to speak of the fore-, mid-, and hind-legs. These members work in two sets of three, on which account insects have sometimes been called "double-three-legged animals". One set includes left fore-, right mid-, and left hind-legs; the other, of course, right fore-, left mid-, and right hind-legs. These sets are advanced alternately (fig. 713), and there is a division of labour between the three legs of each set. The fore-leg pulls the body forwards, the hind-leg pushes it forwards, and the mid-leg is in the main a support, though it also does some pushing work. There must clearly be a certain amount of lateral movement, especially as the body is, so to speak, slung between the legs, as in an Amphibian (see p. 121), and as a result of this the gait is sinuous, the insect

"wobbling" more or less from side to side. These creatures are also experts in varying degree in the art of walking backwards, during which reversal of the usual state of things the fore- and hind-legs exchange their rôles, the former pushing the body back, while the latter pull it back.

At this point the question naturally arises, "Why should an Insect have six legs, while Amphibians, Reptiles, and Mammals have only four?" It has been suggested that the answer to the first part of this question is to be found in the use of the legs of Insects for climbing, six being the smallest number which gives complete stability, and reduces to a minimum the risk of falling. The four-legged condition of ordinary back-boned land animals is, on the other hand, an inheritance from fish-like aquatic ancestors (see p. 117), of which the fore- and hind-fins have furnished the raw material for the evolution of legs. And it would seem that these ancestors acquired four fins rather than any other number because such fore-and-aft projections were best suited for balancing and steering purposes.

Returning to the walk of Insects, it appears that though the three members of each set are placed on the ground together they are not lifted at the same time. Cockroaches, house-flies, and certain beetles raise the hind-leg last, while blow-flies raise it first. We know that in human walking the arms move diagonally, each with the leg of the opposite side. And it is curious to notice that in cockroaches and earwigs the antennæ, and also the sensitive feelers of the second jaws, move diagonally with the legs. The successive limbs of these and other Insects are: *antennæ*, first jaws (mandibles), *second jaws* (first maxillæ). third jaws (second maxillæ), *fore-legs*, mid-legs, *hind-legs*. The first and third jaws do not possess parts which can swing with the legs. In diagonal movements alternate appendages on the same side must move together, and this is the case, for either side, with the appendages of which the names have been placed in italics, and which alternate.

Some Insects have become quadrupeds so far as walking is concerned, as the result of modifications which have affected the fore-legs. In a Praying Mantis, for example, these limbs are adapted for seizing prey (see vol. ii, p. 117), while in a number of Butterflies the same limbs are of small size and are not used in locomotion.

Spiders, Scorpions, &c. (*Arachnida*) as Walkers.—The walking of creatures of this kind is usually more complicated than that of Insects, for there are four pairs of walking-legs instead of three. All of them progress on the tips of the limbs.

In *Spiders* (Araneidæ) the legs are moved on the same diagonal principle as in Insects, but there are here, of course, two sets of *four*, *i.e.* right 1st, right 3rd, left 2nd, left 4th, and left 1st, left 3rd, right 2nd, right 4th. The four legs of a set do not all move at precisely the same time, but successively, either from before backwards, as in a Tarantula, or from behind forwards, as in a House-Spider. After all the legs of one set have executed their movements there is a pause before the legs of the other set begin to move (fig. 714).

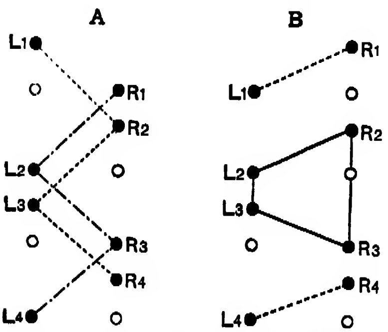


Fig. 714.—Diagram Plans of Phases in Walk of a Spider (A) and a Scorpion (B)

L_1, L_2, L_3, L_4, First, second, third, and fourth legs of left side; R_1, R_2, R_3, R_4, first, second, third, and fourth legs of right side. In A the legs which work together are connected by dotted lines: L_1, R_2, L_3, and R_4 have successively stepped forwards from positions indicated by unshaded circles. In B the legs which keep step are connected by dotted lines; R_1 and R_4 have just moved forwards from positions indicated by unshaded circles. The legs forming central supporting tripod are connected by an unbroken line; of these R_2 and L_3 have just stepped forwards from positions indicated by unshaded circles.

Peculiarities in gait are exhibited by some of those Spiders which hunt down their prey instead of constructing webs. The little Crab-Spiders (*Thomisidæ*), for instance, resemble their namesakes not only in shape but in walk, for they move obliquely forwards instead of directly to the front. In this curious kind of progression the legs of the side which goes first appear to pull the body, while those of the other side push it forwards.

Some of the Jumping Spiders (*Attidæ*) live in the company of ants, which they somewhat resemble in appearance. It is said that they make this resemblance more striking by holding up their first pair of legs to represent the feelers of their associates, walking on the remaining six legs, which are presumably moved in much the same way as those of Insects. This extraordinary sort of mimicry is not supposed, of course, to be the result of conscious intelligence.

Scorpions (Scorpionidæ) move in a somewhat different fashion, which can best be understood by supposing four men walking behind one another in the following way:—The first and last

men keep step, while the second and third keep step neither with one another nor with the first and last, but walk in such a way that their right and left feet are alternately close together. And further, the paces of these two men come between the left and right paces of the others. Supposing a halt to be called when all the men have completed a pace, then if the 1st and 4th men have their left feet advanced, the right feet of the 2nd and 3rd men will be close together, and their left feet far apart. But if, at the moment of halting, the right feet of the 1st and 4th men are advanced, the left feet of the 2nd and 3rd men will be close together and their right feet far apart (fig. 714). Applying this to a Scorpion, and considering for a moment only the 1st and 4th pairs of legs, these keep step, as in the amble of a horse (see p. 144). And it is really these limbs that are of most importance in walking, for the 1st pair pull and the 4th pair push, as do the fore- and hind-legs of an Insect. We have seen that the mid-legs of an Insect act as supports mainly (see p. 166), and this is also the case with the 2nd and 3rd legs of a Scorpion, which act like a progressing tripod, of which the apex (formed by two feet) is alternately right and left.

The Whip-Scorpions (Pedipalpi) and *False Spiders* (Solpugidæ), though possessing the usual eight legs characteristic of their class, agree with the insects in the manner of their walking, which is effected by the last three pairs only of these members, for the first pair are employed as feelers, and may be modified in shape for the purpose (fig. 715).

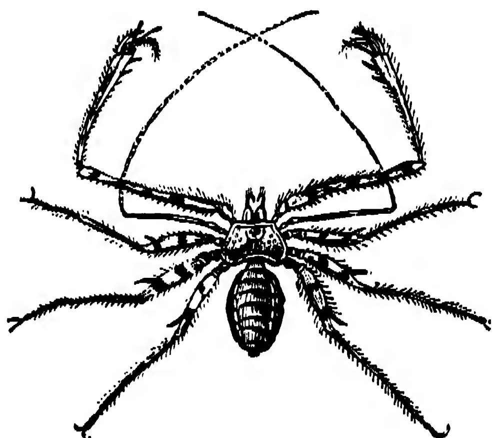


Fig. 715.—A Whip-Scorpion (*Phrynus*)
The first pair of legs are modified into slender feelers, which take no part in walking.

CRUSTACEANS (*Crustacea*) AS WALKERS.—It appears that a Lobster (*Homarus vulgaris*) walks in the same way as a Scorpion, while a Common Prawn (*Palæmon serratus*) commonly uses only six legs for the purpose, and moves them like

Since among the Higher Crustaceans it is the Crabs which have given themselves up most thoroughly to walking as opposed to swimming, and which have also been most successful in converting themselves in some cases into land-animals, we naturally turn to this group for instances of expert progression on firm

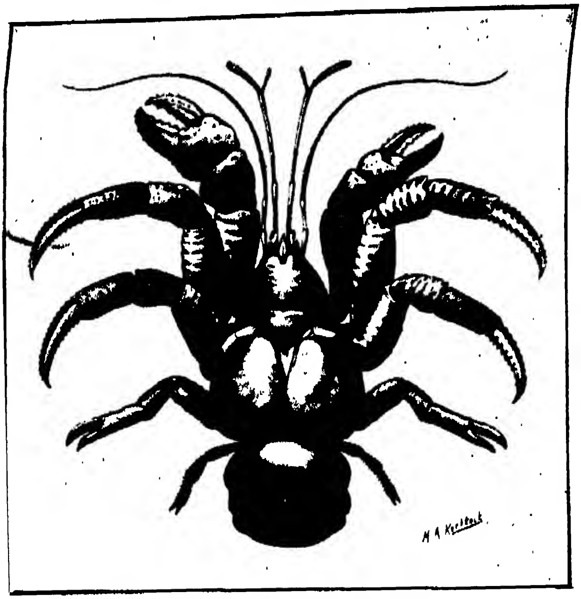


Fig. 716.—Cocoa-Nut Crab (*Birgus latro*)
The last pair of legs are small and take no part in walking.

surfaces. Average Crabs, however, would appear to be distinguished rather by the peculiar nature of their walking than by speed, though some of the ordinary shore forms are able to get along at a good rate. The peculiarity consists in the obliquely forward nature of the gait, and, as in the Crab-Spiders (see p. 168), the legs turned towards the direction of movement for the time being would appear to exert a pulling action, while the others shove the body along. The double tracks produced by this kind of walk constitute one of the most curious objects of interest to be seen on the sea-shore.

As might be expected, the Land-Crabs (*Gecarcinidæ*) are able to progress very rapidly, and the members of a closely-

allied family (*Ocypodidæ*) are in most cases so noted for fleetness that they are commonly known as the Swift-Footed Sand-Crabs. Stebbing (in *A History of Crustacea*) speaks of them as follows:—"As the name *swift-of-foot* implies, these Crustacea are especially noted for their rapidity of movement. They are just the opposite of some of the strong-armed, thick-shelled, slow-moving Cancridæ [of which the common Edible Crab, *Cancer pagurus*, is a type]. On wind-swept stretches of sandy beach, and coloured like the sand, they sometimes seem rather to be borne on the wings of the wind than to run. . . . .

Fig. 717.—Demon-Faced Crab (*Dorippe Japonicus*), much reduced
Note the small size of the last two pairs of legs

Krauss observed in South Africa the species *Ocypode ceratophthalmus* and others, and he says that while they are busy hunting, every now and then they look carefully round, raising their stalked-eyes upright, and standing on tiptoe. At the slightest movement towards them they run with uncommon rapidity to the nearest hole, or, if the danger is too close, press themselves flat on the sand, till an attempt is made to seize them, and then off they dart. In running, they carry their bodies high, doubling and dodging with such speed and cunning, that it is a difficult matter to lay hold of them."

Some of the Crabs and Hermit-Crabs exhibit a reduction in the number of effective walking-legs. In the Cocoa-Nut Crab (*Birgus latro*, fig. 716) of the Cocos-Keeling Islands, for example, we find that the last pair of these members are so small and feeble that the animal has to walk insect-fashion. But reduction may go even further than this, as strikingly exemplified by

the Buffoon Crab (*Dorippe facchino*) of Hong-Kong and the Mediterranean coast, and its ally the Demon-Faced Crab (*D. Japonicus*, fig. 717), rapidly-moving forms which appear to have practically become quadrupeds in the interests of effective locomotion. For in them the two first pairs of legs are very long and strong, while the others are not only small, but attached to the body so high up that they are useless for walking purposes.

CHAPTER XLVII

MUSCULAR LOCOMOTION OF ANIMALS—LEAPING AND HOPPING

We have seen that in the different varieties of Walking the body is never entirely off the ground, while in the various modes of Running it is projected into the air for a short time at regular intervals. From this we naturally pass to Leaping or Jumping, where such projection is much more marked, and a curve drawn to represent the successive positions of any part of the body, say the head, would present a series of sharp convexities and concavities, the crests of the former corresponding to the maximum heights reached above the ground, and the lowest part of the concavities corresponding to the moments when the body actually rests upon the ground. Such a curve for an animal like a kangaroo would differ very greatly from the gentle undulation expressing the vertical movements which take place during walking (see p. 162), while a running curve would be of intermediate character.

It will be convenient to consider here not only that kind of Leaping which is employed for regular onward progression, but also springing movements of more irregular and occasional kind, some of which may be directed to a special object, such as the clearing of an obstacle in the case of a horse, or the seizing of prey by a lion, while other leaps again may be of somewhat aimless character, such as those often performed by the little crustaceans known as sand-hoppers.

But whatever purpose leaping may serve in a particular instance, or however different it may appear to be in diverse animals, the principle of the movement is always the same. Before a leap is taken, the part by which it is effected is bent, and then by a sudden straightening a push of such vigorous nature is given against the underlying surface that the animal

is hurled, as it were, into the air, or it may be water. This alternate bending and straightening may take place in the body itself, in some of the limbs, or in structures of special kind, for some animals devoid of limbs in the ordinary sense may nevertheless possess springing organs. We will first consider typical cases of Backboneless Animals (*Invertebrata*) endowed with leaping powers, and then discuss some of the Backboned animals (*Vertebrata*) which best illustrate the same kind of movement.

BACKBONELESS ANIMALS (INVERTEBRATA) AS LEAPERS

We are here chiefly concerned with some of the Jointed-Limbed Invertebrates (*Arthropoda*) and a small number of Molluscs (*Mollusca*).

JOINTED-LIMBED INVERTEBRATES (*Arthropoda*) AS LEAPERS. Springing powers being related to a firm underlying surface, it is naturally among thoroughly terrestrial groups that we should expect to find them best developed. Insects constitute such a group, and some members of the class can leap higher and further in proportion to their size than any other animals. But there are also a few shore-dwelling Crustaceans and certain spiders which are more or less expert in this sort of movement, and these it will be convenient to consider first.

CRUSTACEANS (*Crustacea*) AS LEAPERS.—Springing powers of no mean order are possessed by some of the Amphipods, a division of Sessile-eyed Crustaceans (Arthrostraca), which includes *Sand-Hoppers* and their allies. Taking as an example the Common Sand-Hopper (*Talitrus locusta*, fig. 718), which literally swarms between tide-marks on many parts of our coast, the body will be seen to have a somewhat shrimp-like appearance, but to be greatly flattened from side to side. The numerous distinct rings of which it is composed give an extreme flexibility, and the hinder region can be bent sharply round so that the tail is brought into contact with the under surface. If now the animal suddenly and vigorously straightens itself it will be hurled into the air to a considerable height. On warm summer days the writer has often seen

Fig. 718.—Common Sand-Hopper (*Talitrus locusta*), enlarged

a sort of haze quivering above the surface of sandy shores, an appearance caused by tens of thousands of these little creatures leaping about in all directions. To say that a Sand-Hopper half an inch long can spring to the height of 6 inches, *i.e.* twelve times the length of its body, is but to give a moderate estimate of the facts. We should consider it somewhat astonishing if a man 6 feet high could spring 72 feet into the air as an every-day proceeding.

Some of the *Crabs* are able to spring with facility, by means of first bending and then suddenly straightening their legs. Hickson (in *A Naturalist in Celebes*) thus describes a case of the sort:—"The rocks which lie below high-water mark are covered with a fine layer of acorn-shells. Upon them may be seen a number of brilliant little green-and-yellow crabs and jumping fishes. The crabs are called by naturalists *Grapsus varius*. They are curiously marked with dark olive-green stripes alternating with bright-yellow stripes and spots, and they are capable of making the most extraordinary leaps and bounds I have ever seen in crab-life. They would spring from rock to rock with the greatest skill and precision, and when a broad expanse of bare rock allowed it they would scamper along at such a rate that I found it impossible to catch them. Not being endowed with the wisdom of the crab, I wondered why, to escape from such an enemy as they evidently took me for, they did not immediately plunge into the water and hide beneath the rocks. Perhaps they have found that it is safer to trust to their powers of flight from rock to rock, which were, it is true, good enough for such an enemy as I was, than, by plunging in the waters, to run the risk of falling victims to larger crabs and other foes that lurk in the rocky pools."

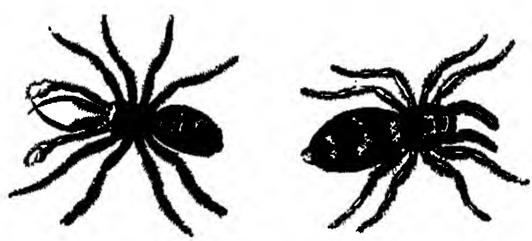


Fig. 719.—Jumping Spiders (*Salticus scenicus*), enlarged

Spiders (*Arachnida*) as Leapers (fig. 719).—The Jumping-Spiders (*Attidæ*) are small forms which, instead of snaring prey by constructing webs, patiently stalk their quarry, terminating the proceeding by a sudden spring which usually attains the desired end. No doubt this leap is effected in the

characteristic manner, by bending the legs first and then suddenly straightening them, but exact details have yet to be learned.

INSECTS (*Insecta*) AS LEAPERS.—A considerable number of springing Insects are known, belonging to various groups. The most primitive of these are undoubtedly the little wingless creatures known as *Spring-Tails* (Collembola, fig. 720), which are found in holes and corners in almost all parts of the world.

Fig. 720.—Spring-Tails (*Podura villosa*), enlarged

They possess a curious springing organ, shaped like a two-pronged fork, which is attached to the tip of the tail, and when not in use is folded up under the body, there being in some cases a sort of "catch" for holding the prongs close to the body, by which a premature leap is prevented. When, mainly as the result of elasticity, the spring straightens out, the Insect is somewhat violently thrown into the air, an act which appears to be more of the nature of a protective measure than a regular means of progression. A well-known species, abundant on the ice in Alpine regions, is popularly known as the Glacier-"Flea" (*Desoria glacialis*) on account of its springing propensities.

Among the *Straight-winged Insects* (*Orthoptera*) considerable leaping powers are possessed by Locusts, Grasshoppers, Crickets, and their allies. The Green Grasshopper (*Locusta viridissima*, fig. 721), one of our native insects, may be taken as a good example. The hind-legs are here the leaping organs, and they are very much larger than the others, while the region known as the thigh (femur) is especially stout and muscular. We have seen that in running animals the hind-limbs are better developed than the others, because their position enables them by sudden and vigorous straightening to give sufficiently powerful backward pushes against the ground to project the animal into the air (see p. 146). For effective leaping there has been an exaggeration of the same kind of action, and it is therefore but natural that the hind-limbs of so accomplished a leaper as a Grasshopper should have attained extraordinary size and strength. It is difficult to catch creatures of this sort by straightforward

chasing, and it is very easy to lose sight of them among the vegetation they inhabit, with which they closely harmonize as to colour.

Beetles (*Coleoptera*) furnish a number of instances of leaping or springing forms. This is the case with the little *Click-Beetles*,

Fig. 721.—Green Grasshoppers (*Locusta viridissima*)

or *Skip-Jacks* (*Elateridæ*, fig. 722), of which many kinds are found in cultivated fields, their larvæ being the notorious "wire-worms". Most of these beetles possess a curious springing apparatus, by which they are able to right themselves if they happen to fall upon their backs. The leg-bearing region of the body (thorax) consists, as in Insects generally, of three rings or segments, upon the under side of which the springing organ is situated. It consists of a spine projecting back from the first segment and fitting into a groove in the second segment. If now the Click-Beetle finds itself upon its back, it draws in the legs and folds the antennæ against the sides, next arching the body so as to pull the spine as far out of the groove as possible (fig. 723). By a vigorous effort the spine is then driven forcibly into the groove, so that the insect's back comes into sudden and violent

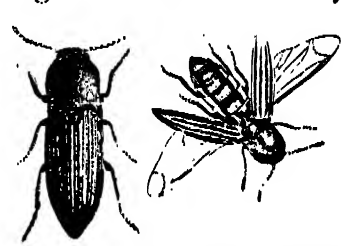


Fig. 722.—Click-Beetles or Skip-Jacks. Actual size indicated by the vertical line on the left.

contact with the underlying surface. The result is a sort of spring which hurls the beetle into the air, when, after describing one or more summersaults, it alights safely on its feet.

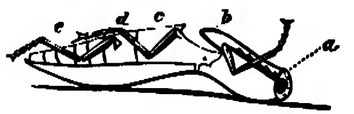


Fig. 723.—Click-Beetle lying on its back and about to spring. *a*, Head; *b c d*, rings of thorax; *e*, abdomen. The leaping-spine is shown at *b*. (Enlarged.)

The *Flea-Beetles* (*Halticidæ*) are also agricultural pests, the leaping powers of which are indicated by their name. A common species is the Turnip Flea-Beetle (*Haltica nemorum*, fig. 724), and we find here, but in lesser degree, the same kind of arrangement as in a Grasshopper. That is to say, the hind-legs are the best developed, but they are characterized by strength rather than length.

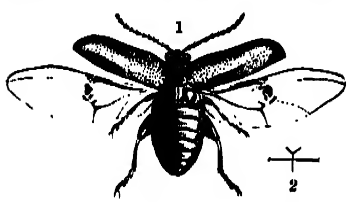


Fig. 724.—1, Turnip Flea-Beetle (*Haltica nemorum*), enlarged; 2, actual size of the same.

The *Fleas* (*Pulicidæ*), which are commonly regarded as aberrant wingless members of the order of Two-winged Flies (*Diptera*), are, of course, notable leapers. It has indeed been asserted that for a man to jump right over St. Paul's Cathedral would be a performance about equivalent to the saltatory feats of the Common Flea (*Pulex irritans*), taking into account the relative size of the two gymnasts. The hind-legs of a Flea are well-developed in relation to the characteristic mode of progression (fig. 725).

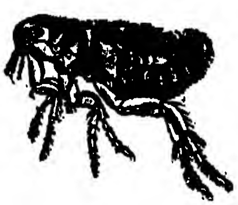


Fig. 725.—Common Flea (*Pulex irritans*), enlarged

Before leaving the two-winged flies it may be noted that the limbless maggots, which represent their early stages of life, are often able to spring with facility, of which a well-known example is afforded by the larvæ of the Cheese-Fly (*Piophilus casei*). The movement is brought about by sudden straightening of the body, which has previously been bent into a sharp curve.

Of insects belonging to the order of *Bugs* (*Hemiptera*), those included in the *Froghopper Family* (*Cercopidæ*) are noted for their leaping powers, in accordance with which the hind-legs are large and muscular. The frothy masses familiarly known as "cuckoo-spits" are the abodes of the larvæ of certain common species of these small insects.

Annandale has recently discovered a very remarkable leaping-

mechanism in some of the widely-distributed tree-bugs known as Lantern-Flies, of which the Chinese Lantern-Fly (*Hotinus candelabrius*) (fig. 726) is a common species. In these insects the front of the head is drawn out into a "nose" of portentous length, which was formerly supposed to be luminous. Hence the popular name, which may perhaps turn out to be justifiable for some species. The nose is hollow and very elastic, and there is a transverse joint running across the middle of it, permitting its end half to be bent up. Supposing a Lantern-Fly which has

Fig. 726.—Chinese Lantern-Fly (*Hotinus candelabrius*)

settled on a branch suddenly wishes to leave its perch, the following appears to be the method adopted. The head is rapidly pressed down against the branch so as to bend up the nose. This organ then straightens itself again by elasticity, which results in a vigorous push against the underlying surface. As the legs give a "shove off" at the same time, the insect is launched into the air with considerable force. Annandale thus describes this peculiar kind of leaping as observed in a Malay species of Lantern-Fly:—". . . I noticed a specimen of *Hotinus spinolæ* seated on the trunk of a Durian tree in the village, and incautiously attempted to catch it in my hand. The insect remained almost still, merely drawing in its legs towards its body and pressing the claws firmly against the bark, until I had almost

touched it. Then it lowered its head with very great rapidity, flew up into the air without spreading its wings, and alighted upon the roof of a house about six feet beyond the tree and considerably higher than the position on the trunk whence it had started." It is pretty clear that we have here a device for furthering escape from enemies.

MOLLUSCS (MOLLUSCA) AS LEAPERS.—Springing powers are possessed by some of the Bivalves and also by certain kinds of Snail, though such forms are in a small minority, as most Molluscs either swim, or creep, or burrow.

Bivalve Molluscs (*Lamellibranchia*) *as Leapers.*—Perhaps the most typical springing bivalves are the members of the *Cockle Family* (*Cardiidæ*), such as the Common Cockle (*Cardium edule*) and its allies. In these creatures the muscular foot is long,

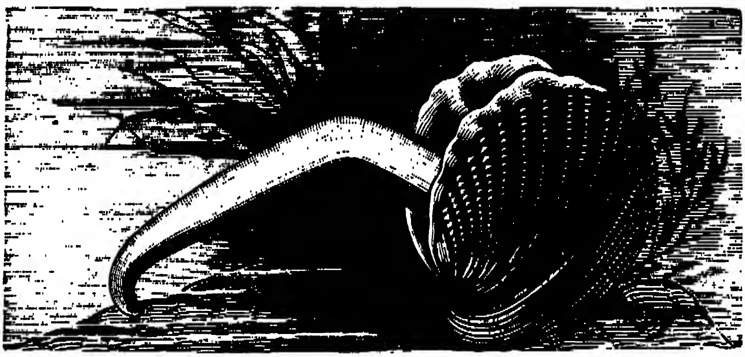


Fig. 727.—Cockle (*Cardium*). The long bent foot is protruded

narrow, and sharply bent in a knee-like fashion (fig. 727). It is this foot which constitutes the springing organ, and it acts on the principle of which so many examples have already been given. That is to say, it is suddenly and vigorously straightened, pushing back with such force against the underlying sand that the body is thereby projected obliquely upwards and forwards.

Snails (*Gastropoda*) *as Leapers.*—In the *Wing-Shells* (*Strombidæ*, fig. 728) the hinder part of the foot is narrow and bent, enabling this region of the body to be used for springing purposes, after the fashion of Cockles.

Some of the *Land Snails* are also able to spring on occasion, the object being escape from enemies (see vol. ii, p. 373). Our little native Glass Snail (*Vitrina pellucida*), for instance, if alarmed when crawling exposed to view on a stone or the like,

is able to suddenly bring down the hinder part of its foot on the underlying surface with such force as to jerk the animal on to the ground, where it has a chance of falling into some corner or crevice hiding it from view. A much more remarkable case has been described by Semper (in *Animal Life*) of certain small Philippine land-snails (species of *Helicarion*), which, when attacked or frightened, actually throw off this "tail" after it has served the purpose of jerking them on to the ground. This

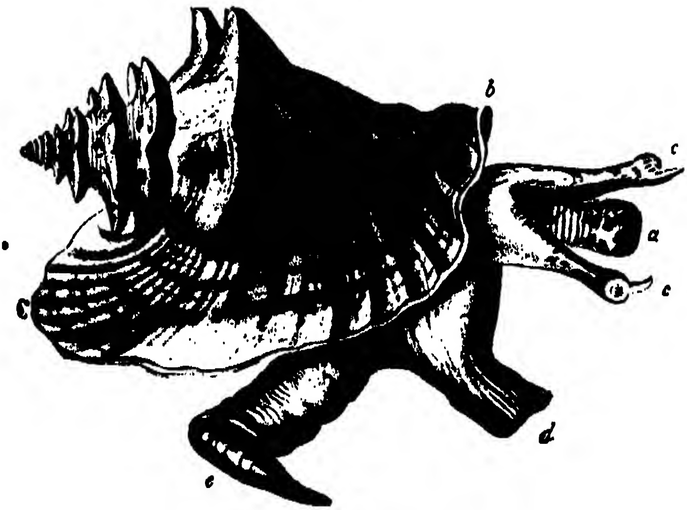


Fig. 728.—Wing-Shell (*Strombus*)
a, Proboscis; *b*, notch in mouth of shell; *cc*, tentacles with eyes; *d*, front part of foot; *e*, sharply bent hind part of foot bearing a shelly plate (operculum).

is Semper's account:—"The numerous species . . . live on trees in damp woods, often in great multitudes; they are very active, and creep about with considerable rapidity upon the twigs and leaves of the trees. Every species that I personally examined possessed the singular property, which many lizards have—particularly the Geckoes,—of shedding their tail when they are seized somewhat roughly, at a little way behind the shell. This they do by whisking the tail up and down with extraordinary rapidity, almost convulsively, till it drops off; if the creature is held by the tail, it immediately falls to the ground, where it easily hides among the leaves. If it is laid flat on the hand, the rapid wagging movement is strong enough to raise the body with a spring into the air, so that it falls over on the ground. These snails at first constantly escaped me and my collectors in this way, and not unfrequently we had nothing but the tail left in our hand."

BACKBONED ANIMALS (VERTEBRATA) AS LEAPERS

Under this heading we shall have to successively consider various kinds of Leaping, Springing, and Hopping, as found among Fishes, Amphibians, Reptiles, Birds, and Mammals.

Fishes (Pisces) as Leapers or Springers.—It is a matter of familiar observation that many Fishes are able to leap or "rise" out of the water to a greater or less height, one of the most notable instances being that of the Salmon (*Salmo salar*). As everyone knows, this fish annually ascends some river or other for the purpose of spawning, and during this progress is able to spring right over weirs or falls which may be as much as 10 feet high. The leap is mainly effected by the powerful tail, which is brought down on the water with a tremendous smack that sends the salmon flying into the air. During this act the strongly-curved body is straightened out, and this, no doubt, increases the power of the leap.

The shore-haunting Mud-Skippers (see vol. ii, p. 87) of the Indian Ocean are able to get along with considerable rapidity by means of a succession of short leaps, partly effected, it would seem, by the alternate bending and straightening of the body, but chiefly by means of the pectoral fins, which are unusually muscular and well-developed. The leaps are sufficiently powerful to hurl the body several inches into the air.

Fig. 729.—Grass-Frog (*Rana temporaria*)

Amphibians (Amphibia) as Leapers.—The Tailless Amphibians (Anura), *i.e.* Frogs, Toads, and their allies, are pre-eminent as leapers, and their structure is greatly specialized in adaptation to this habit. Taking as a common example the Grass-Frog (*Rana temporaria*, fig. 729), we notice that the short, compact body is entirely devoid of tail, while the hind-limbs are of relatively enormous length and very muscular. It is these limbs

which are the agents of leaping. When the animal is resting in a natural posture, as shown in the figure, their successive parts are folded upon each other, the knee being directed outwards and forwards, while the ankle points to the back. It is clear that a sudden straightening out must propel the small, compact body forwards with great force, and, since the backward push is given obliquely downwards, the animal rises to a considerable height into the air. Examination of the skeleton (fig. 730) shows how well it is adapted to leaping. The two long hip-girdles are united together at the back, thus bringing the hip-joints close together, so that when the hind limbs are straightened at the same time there is no waste of force in side-pushes. The tips of the girdles are attached fairly far forwards, to the last distinct vertebra (sacrum) of the backbone, at points where the forward pushes will have most effect. In the framework of the free parts of the limbs we see that in the interest of firmness the two bones of the lower leg (tibia and fibula) have completely fused together, while the foot is of great relative length. The presence of a lot of little bones or cartilages in the ankle-region (as in a Newt) would greatly militate against firmness, and to obviate this most of these elements have been either greatly reduced or suppressed altogether, except two, and these are long and strong, besides which they are firmly united together at both ends.

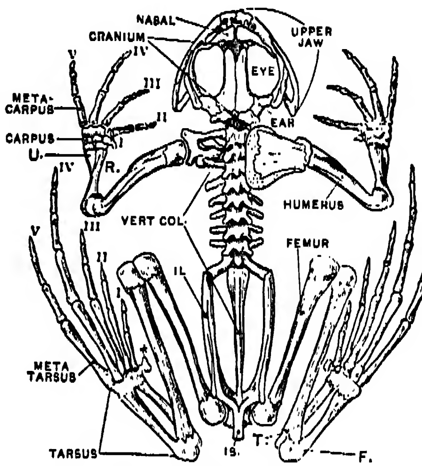


Fig. 730.—Skeleton of Frog

I–V, Digits; * extra digit (calcar) of foot; R, radius; U, Ulna; IL and IS, parts of hip-girdles; T, tibia; F, fibula; VERT.COL., vertebral column (backbone).

The Frog's leaping powers are useful not merely as a means of progression and for escape from enemies, but also in the capture of prey. Gadow (in *The Cambridge Natural History*) gives the following very interesting account of the habits of this animal, the extracts being selected with reference to the uses of its leaping powers:—"The Grass-Frog, when pursued, rarely takes to the water for safety. It trusts to flight, first by

a few long and fast jumps, and then to concealment by squatting down between grass, under leaves; it rarely creeps into a hole, even if there be one near. The jumps soon become shorter and shorter after a few dozen repetitions. . . . The food, which consists chiefly of insects, snails, and worms, must be moving to excite interest; then the Frog, whose favourite position is half-squatting, half-supported by the arms, erects itself, and, facing the insect, turns round upon its haunches, adjusts its position anew by a shifting of the legs, and betrays its mental agitation by a few rapid movements of the throat. All this time the prey is watched intently till it moves; then there follows a jump, a flap of the tongue, and the insect is seen no more. As a rule these frogs do not crawl, they jump or hop even whilst stalking, and this takes place at any time of the day; in fact they are very diurnal, although they become more active towards the evening. When caught they are at first very wild, and, like all true frogs, very impetuous, committing acts of astonishing stupidity, without any apparent sense or appreciation of distance or height. The captive will not only jump off the table—whilst a toad stops at the edge and looks carefully down,—but without hesitation he jumps out of the window, regardless of the height above the ground. This is due to sheer fright; he loses his head. When at large in his native surroundings, nothing will induce him, although hotly pursued, to commit suicide by jumping down a precipice. But all this wildness calms down wonderfully soon. The captive no longer dashes his head against the glass; he does not struggle or twist when taken up; on the contrary, he makes himself at home, watches your coming with intense expectation, and without hesitation accepts the proffered meal-worm, maggot, butterfly, or earthworm; in short, he shows what a jolly and intelligent fellow he really is."

REPTILES (REPTILIA) AS LEAPERS.—Among existing forms there are no very interesting arrangements for effecting leaping, if we except the curious springs that some of the poisonous Snakes (*Ophidia*) appear to be able to make when seizing prey or defending themselves at close quarters. Under such circumstances the body can be coiled up and then suddenly extended, so that the snake is projected into the air.

Many Lizards (*Lacertilia*) are also able to leap with considerable facility, the hind-limbs being used for the purpose in the

usual way, and the tail giving also some assistance by way of steadying the body, if it does not actually help in propulsion.

Birds (Aves) as Leapers.—There is no doubt that Birds have sprung from a reptilian stock, though we unfortunately know too little to feel sure of the stages by which the evolution has taken place. It is, however, not improbable that the immediate reptilian ancestors were springing or hopping forms, in which the hind-limbs were well-developed, and served as the chief means of progression. If this be so, the springing or hopping gait which is characteristic of many birds must be regarded as the primitive method of locomotion for members of the class, while walking was a later acquisition. A view of this kind harmonizes with the very specialized nature of the legs of Birds.

Fig. 731.—Two Hopping
1, Chiffchaff (*Phylloscopus rufus*); 2, Wheatear (*Saxicola œnanthe*).

The word "hopping", as applied to human beings, means progression by a series of leaps on one foot, but in the case of Birds it signifies locomotion by means of a succession of relatively short jumps taken from both feet together. Hopping in this sense is practised by a large number of familiar forms, among which are included Thrushes, Blackbirds, Wheatears (fig. 731), Hedge-Accentors (Hedge-"Sparrows"), Robin Redbreasts, and Wrens. By measuring snow-tracks, R. Kearton estimated that the average hop of a Blackbird was 9 inches, as compared with 6½ inches for the average stride of a Rook. Although this kind of movement is very common among small birds that hunt for food upon the ground, many of them do not hop, but run, as is the case with Wagtails. Indeed walking and running are characteristic of those forms which have become best adapted

to life on the ground, and fly comparatively little or not at all. Rails and Ostriches will serve as examples of this. Some birds, *e.g.* Rooks, both hop and walk.

For progress over very uneven surfaces hopping is particularly well suited, and the small Crested Penguins (species of *Eudyptes*), which when on land constantly have to make their way over rough boulders, are called " Rock-Hoppers " on account of their expertness in this direction.

It may further be observed that when birds take to wing from the ground they give a preliminary jump, which launches them fairly into the air. So important is this leaping start that the feeble-legged Swifts are often believed to be unable to rise from the ground at all. Competent observers deny the truth of this, though birds with short legs and very long wings must be at some disadvantage in the matter. Aflalo (in *Natural History of the British Isles*), speaking of our native Swift (*Cypselus apus*), says:—" It is not often seen to alight, though I have caught a few, a very few, in the act of dusting themselves in Kentish lanes, from which, in spite of the length of their wings, they can rise without quite so much difficulty as some chroniclers would have us imagine ".

MAMMALS (MAMMALIA) AS LEAPERS.—We have had occasion to note that the best runners in this class are distinguished by marked development of the hind-limbs as compared with the fore- (see p. 141), the reason being that the former do most of the work. Since leaping involves an even more vigorous use of the hind-limbs, we should expect to find the fleeter Mammals also well off as regards powers of leaping. This is usually the case, and some of the best examples are furnished by rock-dwelling members of the family of Hoofed Mammals (*Ungulata*), such as wild Sheep and Goats, Chamois, Ibexes, and the like. Creatures of this kind are able to spring from crag to crag in a very astonishing way, as hunters have reason to know. Brehm (in *From North Pole to Equator*) thus describes the movements of the large Archar Sheep (*Ovis Argali*, fig. 732) of Central Asia:—" Among the rocks they move, whether going upwards or downwards, with surprising ease, agility, and confidence. Without any apparent strain, without any trace of hurry, they clamber up and down almost vertical paths, leap wide chasms, and pass from the heights to the valley almost as if they were

birds and could fly." The Rocky Mountain Sheep, or Bighorn (*Ovis montana*), is also capable of making extraordinary leaps, and will spring over a sheer precipice 10 to 15 feet deep without hesitation, always provided there is suitable foothold at the bottom, and for this a very little serves.

Many of the Hoofed Mammals specialized for swift running on level surfaces are also expert leapers, none more so than the Antelopes. The Springbok (*Gazella euchore*) is quite remarkable

Fig. 732.—Archar Sheep (*Ovis Argali*)

for its leaping powers, to which the popular name is an allusion. When suddenly alarmed it springs high in the air, assuming attitudes which are far from graceful, possibly as the result of intense muscular action. But indeed it may be said generally that many of the positions of swift animals in movement, as revealed by the camera, are not nearly so pleasing as the conventional postures by which they are rendered in some pictures, some of which render with sufficient accuracy the impression made upon the eye. The remark about the Springbok has reference to the general effect as thus given. Millais, who has studied this animal in its native wilds, thus describes its movements (in *A Breath from the Veldt*):—"I camped out on the

Karroo for a fortnight for this express purpose [*i.e.* study of the movements], where, with the aid of a powerful telescope, I could observe them from my tent door at all hours of the day. The peculiarity which struck me most was the stiff manner in which the legs are held in all cases of extreme movement. It is only when the buck is walking very slowly, and feeding as he goes along, that the joints seem to be relaxed, all his quicker and more energetic motions being performed from the shoulders and thighs in a constrained and 'collected' manner. I would especially call the attention of naturalists to this peculiarity on the part of the Springbuck and nearly all the South African antelopes I have observed. I do not consider that antelopes under *movement* have ever been correctly treated by any artist. Antelopes on the move are generally given the graceful movements of deer, whereas, with few exceptions, all their paces are performed with a certain stiffness and contraction of the limbs that are the reverse of graceful."

Of smaller animals which are fleet of foot, and at the same time endowed with considerable springing powers, the Hare (*Lepus timidus*) and its kind deserve mention among Gnawing Mammals (*Rodentia*). Here again we find that the hind-limbs are of disproportionate length and strength.

So far we have considered leaping as exhibited by Mammals whose powers of locomotion are mainly used in retreat from enemies, but among the cat-like species of Flesh-eating Mammals (*Carnivora*) springing is an important factor in securing prey (see p. 10). Such an animal first assumes a crouching attitude, in which the sections of the hind-limbs are strongly bent upon one another. By a sudden and powerful muscular effort these limbs are then extended, pushing back with such force against the ground that the animal is propelled forward like an arrow from a bow. Further details are here unnecessary.

We now have to deal with certain Pouched Mammals (*Marsupialia*) in which leaping constitutes the regular mode of progression, and which are greatly modified in structure in correspondence with this. Among such forms the Kangaroo presents a very typical case. This animal is practically a biped as regards progression, but the long, muscular tail is of great importance by way of balancing and steadying the body. It also helps to support its owner when in a resting attitude, supplementing the

Fig. 733.—Red Kangaroo (*Macropus rufus*) in resting attitude. From an instantaneous photograph

under surfaces of the long feet, which are provided with horny thickenings of corresponding length. This attitude is shown in fig. 733, which is taken from an instantaneous photograph of the Red Kangaroo (*Macropus rufus*). The striking disproportion between fore- and hind-limbs is also well seen in the same figure. The thigh, which is not particularly long, is largely enclosed within the boundaries of the trunk, as in other cases elsewhere described (see p. 134), but the lower leg is of quite extraordinary length, and the foot is also considerably elongated. As will be gathered from fig. 734, in which the skeleton is represented, a reduction of digits has taken place, in the interests of firmness. The great toe has gone altogether, while the second and third digits are extremely slender, bound up in a common fold of skin, and of no use in locomotion. On the other hand, the fourth and fifth digits, especially the former, are very large, and their instep-bones very long. There are only three bones belonging to the ankle (tarsus) which are of any size, and these are large and firm, and so connected as to prevent any "giving" in this region. Though both bones of the lower leg (tibia and fibula) are present, they are united with sufficient firmness to prevent this being a source of weakness.

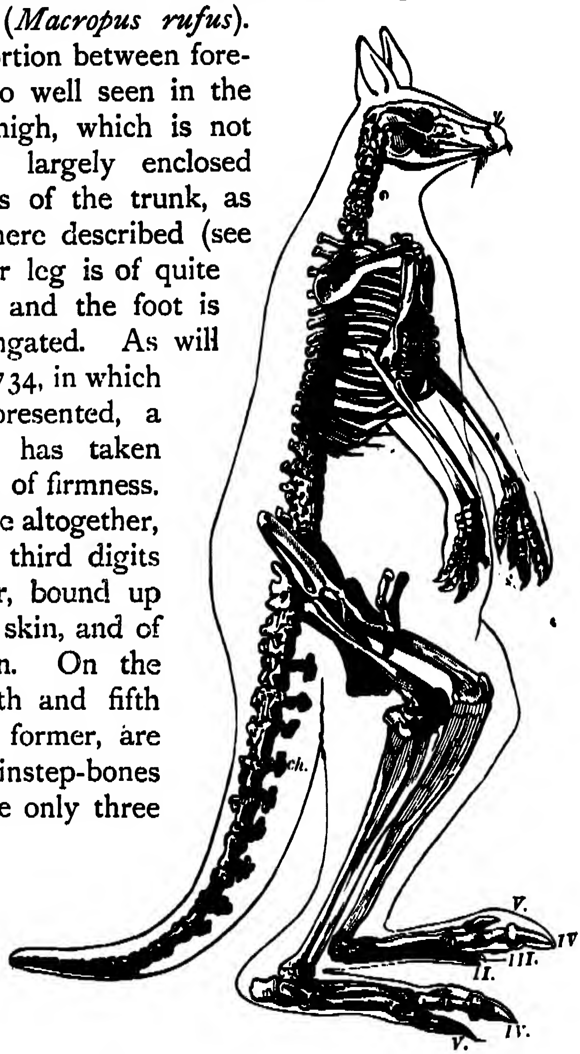


Fig. 734.—Skeleton of Kangaroo. II–V, Digits of foot

The relatively short fore-limbs of the Kangaroo possess the full complement of five digits, and they are capable of considerable lateral movement, as, for example, when employed for

purposes of defence. And, as usually where side-action is marked, there is a strong collar-bone stretching from breast-bone to shoulder-blade, and serving as a firm prop on the inner side. The chief use of the fore-limbs, however, is to support the front part of the body when the animal is grazing, the attitude then assumed being extremely ungraceful. We have elsewhere seen (vol. ii, p. 182) that the kangaroo-like animals present a series of cases in which the disproportionate size of the hind-limbs becomes more and more apparent, leading up to the extreme case just described. Just as, in a lesser degree, the Okapi is intermediate between the Giraffe and other ruminants with shorter necks and limbs (see vol. ii, p. 170). The position of a Kangaroo which has just sprung from the ground is shown in fig. 735.

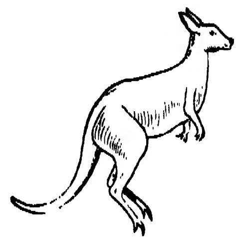


Fig. 735.—Kangaroo at beginning of leap

Kangaroos are not the only Pouched Mammals which are specialized in relation to leaping. The little Australian Bandicoots (*Peramelidæ*) also present us with similar adaptations related to the same habit, though the tail is comparatively short and weak, notwithstanding which it serves the same supporting function as in a Kangaroo. In the majority of these small creatures (species of *Perameles*) the hind-limbs are of similar construction to those of their larger cousins, but the fore-limbs are also much modified, for both thumb and little finger are of insignificant size, while the other three digits are long, and provided with powerful claws. This is related to the habit of digging holes as places of refuge. The Pig-footed Bandicoot (*Chæropus castanotus*, fig. 736) is of special interest, for it is more specialized than its immediate relatives as regards both pairs of extremities. In the hind-limb only one digit (the fourth) is well developed, being long, strong, and provided with an unusually powerful claw. The second and third digits are relatively even smaller than in a Kangaroo, while the fifth or little toe, which is large in that animal, is here greatly reduced. For practical purposes the Pig-footed Bandicoot may be considered a one-toed animal, like a horse, as regards the hind-foot; but it is here the fourth digit which has been retained and enlarged, while in a horse it is the third (see p. 142). The fore-foot is also more specialized

than in an ordinary Bandicoot, and is practically only two-toed, for the first and fifth digits have gone altogether, and the fourth is a mere vestige. The presence of two large digits has earned for this animal the nickname "pig-footed", but the two large fingers of a pig are the third and fourth, while here they are the second and third; and a pig also possesses fairly well developed second and fifth fingers. (see p. 149). When leaping, the Bandicoots keep their fore-limbs pressed well against the body.

Fig. 736.—Pig-footed Bandicoot (*Chœropus castanotus*)

One more springing marsupial requires mention here. This is the Pouched-Jerboa (*Antechinomys laniger*) of Queensland and New South Wales. It is mouse-like in appearance, but with long hind-limbs and well-developed tail. Specialization with reference to leaping has not gone nearly so far as in Kangaroos, for reduction of digits has only affected the great toe, which has entirely disappeared.

Gnawing Mammals (*Rodentia*) *as Leapers.*—Some members of the North American family of Pouched Rats (*Geomyidæ*) are leapers, while the springing habit is eminently characteristic of most of the species included in the family of Jumping Mice or Jerboas (*Dipodidæ*), nearly all of which inhabit Asia or Africa, though the group is also represented in South Europe and North America.

As to the Pouched Rats (*Geomyidæ*) it may not be unnecessary to remind the reader that the first part of their name has reference to the possession of a "cheek-pouch" for the storage of food,

and this has, of course, nothing to do with the pouch of the Pouched Mammals *par excellence* (*Marsupialia*), which is placed far back on the under surface of the body, and is used as a nursery for the immature young. The Common Kangaroo-Rat or Pocket-Mouse (*Dipodomys Phillipsi*, fig. 737) is a small, somewhat mouse-like animal which lives in the desert regions

Fig. 737.—Common Pocket-Mouse (*Dipodomys Phillipsi*)

to the east of the Rocky Mountain Highland, and it possesses the long tail and disproportionately-developed hind-limbs which we have already seen to be characteristic of Kangaroos and the like. But, being a gnawing Mammal, it is but very distantly related to these latter forms, the similarity in general build being the result of adaptation to the same kind of life. Or, to put it technically, we have a case of "convergence" of character in members of totally distinct groups. Just as thoroughly aquatic animals have acquired the same general shape of body, *i.e.* the shape best adapted to rapid progression through water. The

Kangaroo-Rat is not nearly so specialized as regards its hind-limbs as its Australian namesakes. Only one digit has suffered reduction, the first or great toe.

Jerboas (*Dipodidæ*) and their allies present us with a series of increasing modifications in adaptation to expert leaping. In all members of this series the tail and hind-limbs are relatively well developed, while the fore-limbs usually possess the full number of five digits, and since they are not only used to support the body during feeding, but also for burrowing and carrying food to the mouth, it is not surprising to find that fully-formed collar-bones are present (see p. 158). In the hind-limbs it is to be noticed that one bone of the lower leg, the fibula, is more or less reduced, as in some of the swift-running Mammals (see p. 141), on the principle that one large bone furnishes a better support than two smaller ones, while there is a large projection at the back of the heel-bone (calcaneum), which serves for the attachment of important muscles that straighten the leg in the act of springing. Kangaroos always progress by leaping, but these animals are also able to walk, in much the same way as a human being, except that the completely erect attitude is not assumed.

Perhaps the least specialized form as regards structure is the North American Jumping-Mouse (*Zapus Hudsonianus*), which ranges from the frozen north to Mexico. Five distinct toes are present on the hind-foot, but in the fore-foot the thumb is greatly reduced. Lydekker (in *The Royal Natural History*) quotes the following account of the habits of this animal, as observed by R. Slade:—"The Long-tailed Jumping-Mouse inhabits high land or low land, forest or pasture, cultivated field or swamp, and appears to be equally at home in either, and not numerous in any situation. It possesses a momentary agility second to no other rodent, and a muscular strength of enormous power for so small a creature. When suddenly disturbed it often moves away in a direct line, the first three or four leaps being 8 or 10 feet in length, but these distances rapidly decline to about 4 feet. This is not always the case, however, for it frequently takes an irregular course, and jumps at divers angles for several successive leaps, keeping the same general direction, or changing at will. It can double, and quickly too, if pursued, and by its manœuvres and instantaneous squattings can elude

a hawk or an owl, and its spontaneous irregularities enable it to escape being brained by a weasel, or swallowed whole by the common black snake." Since the head and body are only a little over 3 inches in length, it will be seen that the leaps are of very great relative extent.

The Cape Jumping-Hare (*Pedetes Caffer*) is the largest member of its family, being about the size of an ordinary hare, which it somewhat resembles in appearance, except as regards

Fig. 738.—Cape Jumping-Hare (*Pedetes Caffer*)

limbs and tail (fig. 738). The hind-foot has lost the great toe, and the remaining digits, of which the third is best developed, bear thick, blunt nails. The ordinary leaps vary from about 6 to 9 feet, but it is stated that they can be increased on occasion to from 20 to 30 feet.

The remaining members of the family now being considered are generally known as Jerboas, and are particularly characteristic of the steppe and desert regions of Africa and Asia. The less specialized forms of the kind are called Five-toed Jerboas, because the hind-foot possesses the full number of digits, though only the three central ones reach the ground. The instep-bones (metatarsals) of these three toes are closely united, while the corresponding bones of the first and fifth toes have undergone reduction. A typical species is the Siberian Jerboa (*Alactaga*

decumana), a creature about the size of a squirrel, which ranges from Siberia into the steppe-region of European Russia (see vol. i, p. 131).

The Three-toed Jerboas are smaller and more specialized animals, which have altogether lost the first and fifth digits of the hind-limb, while the instep-bones of the three central toes are

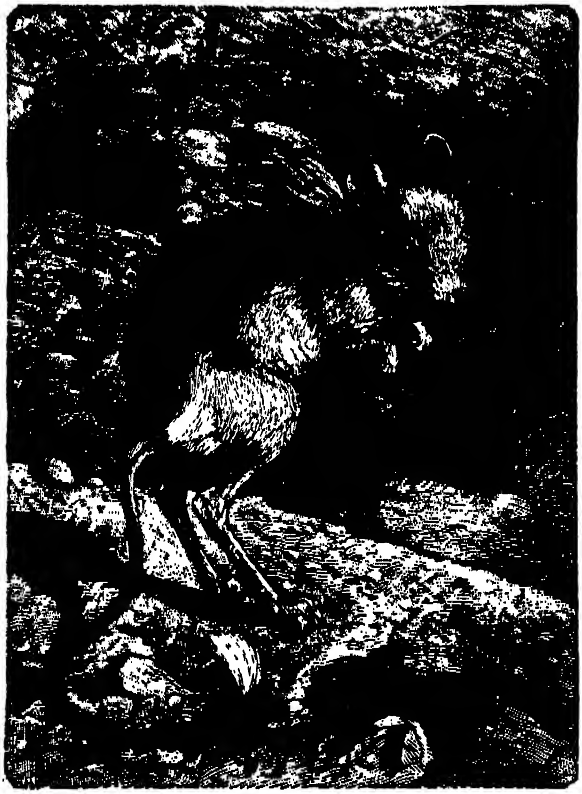


Fig. 739.—Egyptian Jerboa (*Dipus Mauritanicus*)

fused together into a "cannon-bone", reminding us of the fusion of corresponding elements which takes place in a bird (see p. 126). Cannon-bones formed by fusion of two bones are possessed by ruminants (see p. 149), and in all these various cases greatly increased firmness is gained by the arrangement. The best-known species is the Egyptian Jerboa (*Dipus Mauritanicus*, fig. 739), an essentially desert animal which ranges from Algeria to Persia. Of these little creatures Vogt (in *Mammalia*) thus speaks:—"The Jerboas run like long-legged birds, make enor-

mous leaps, and in doing so draw their fore-feet towards their breast or lay them on their cheeks. . . . The three toes of the hind-feet are protected against the heat of the sand by small bunches of hair. The fine thick fur has the colour of the desert sand. The animal is especially fond of the alfa-covered steppes, lives socially, and digs holes of no great depth, which communicate with one another."

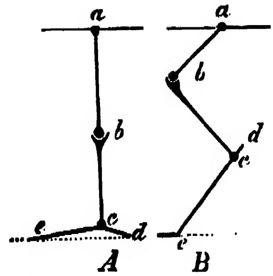


Fig 740. Diagram to illustrate relative length and position of regions in hind-limbs of Man (A) and Jerboa (B). *ab*, Thigh; *bc*, lower leg; *ecd*, foot. The knee-joint is at *b* and the ankle-joint at *c*; *d*, heel.

Some of the differences between the leg of a human being and the leg of a Jerboa, as to proportion of parts, and the positions assumed by them in a state of rest, are represented diagrammatically in fig. 740.

Insect-Eating Mammals (Insectivora) as Leapers.—One family of this widely-distributed and primitive order includes specialized leaping forms. These are the Jumping-Shrews (*Macroscelididæ*), native to the plains and deserts of Africa. A well-known South African species is the Cape Jumping-Shrew (*Macroscelides typicus*, fig. 741), often called the "Elephant" Shrew on account of its long, flexible snout. This feature at once distinguishes it from a Jerboa, which it otherwise resembles in general proportions. The long hind-limbs possess the full number of toes, although the

Fig. 741.—Cape Jumping-Shrew (*Macroscelides typicus*)

first is small, and no fusion has taken place between the instep-bones.

The Rock Jumping-Shrew (*M. tetradactylus*) of East Africa is a rather larger form which lives in rocky places, and it is somewhat more specialized, having completely lost the great toe.

CHAPTER XLVIII

MUSCULAR LOCOMOTION OF ANIMALS—BURROWING

Having now considered at some length a variety of forms which live on the surface of the sea-floor or on the ground, and progress by creeping, walking, running, or leaping, we naturally turn to those animals which live in the ground, or in marine and freshwater deposits of sand, mud, &c. Where the material is sufficiently firm these burrowing forms may construct more or less permanent underground "roads", which are from time to time extended; while in other cases burrowing is carried on continuously, and the passages excavated fall in as soon as they are made. In this chapter we are only concerned with creatures that live always or largely underground, or within the deposits that accumulate under water. Temporary or permanent excavations that serve as homes or retreats will be dealt with further on under Animal Dwellings.

Burrowing animals of thorough-going kind are found both among the Backboned Animals (Vertebrata) and Backboneless Animals (Invertebrata), and, as in other cases, these will be considered under separate headings.

BACKBONED ANIMALS (VERTEBRATA) AS BURROWERS

Typical underground species are found among Mammals (Mammalia), Reptiles (Reptilia), Amphibians (Amphibia), and Fishes (Pisces), as also among Primitive Vertebrates (Protochordata).

MAMMALS (MAMMALIA) AS BURROWERS.—Burrowing would seem to be a very ancient habit among land vertebrates, and has been attended with two advantages—rendering fresh food supplies available, and at the same time warding off the attacks of enemies. So far as the food existing underground consists

of lower animals, some of these no doubt led the way to this kind of life, partly as a protective measure, the value of which has since been largely reduced by the fact of their example having been followed by some of their enemies. We find, for example, that insect larvæ often live underground, the habit having no doubt been acquired with reference to the food there to be found, and the immunity from attack enjoyed at the same time. But the adoption of the subterranean habit in creatures of this sort added greatly to the richness of the underground larder, and was no doubt one of the factors in the evolu-

Fig. 742.—Common Mole (*Talpa Europæa*). (From an instantaneous photograph)

tion of Moles and other forms adapted to make the most of the gastronomic advantages offered. A similar case has already been discussed (see vol. ii, p. 327) in speaking of the flight of insects, for by the acquisition of flying powers these animals were at first protected in a much higher degree than they have been since the evolution of Birds and Bats.

That the element of safety in an underground life had much to do with the evolution of burrowing Mammals appears very probable when we remember that the most thorough-going subterranean members of the class belong to the weaker and more primitive orders, and have therefore been specially subject to persecution by predaceous forms. The most highly-specialized burrowing Mammals, indeed, are to be found among insectivores, rodents, and marsupials.

Insect-eating Mammals (Insectivora) as Burrowers.—It would

be difficult to select a better example of an animal thoroughly adapted to an underground life than the Common Mole (*Talpa Europæa*, fig. 742), a form with which almost everybody is acquainted. The nearly cylindrical body and the conical head, between which there is a scarcely appreciable neck, are well suited by their shape for easy passage through the surrounding earth. The same end is also furthered by the dense velvety fur, of which the short hairs grow out vertically, so as to yield equally in all directions (fig. 743). The powerful fore-limbs are largely included in the outline of the general body, and terminate in bare, hand-like extremities, provided with strong, curved claws (fig. 744). The palms are directed outwards and backwards, and we may say that in all respects these limbs are admirably efficient digging organs, by which the earth is excavated and thrown backwards. A life almost entirely underground is here, as usually, associated with very small eyes, and these organs are so hidden in the fur that they are only to be found with some difficulty. Large eyes would not only be useless, but would also be very liable to injury. It is equally difficult to detect the small ear-openings, these being similarly hidden. They are entirely devoid of external ear-flaps, which are just as unsuitable for a burrowing life as for an aquatic one (see p. 69). The tail is short and the hind-limbs are comparatively feeble. We have, in fact, as to this point, exactly the opposite state of things to that which is found among the most highly-specialized leapers (see p. 186).

Fig. 743.—Diagram Sections through Skin of a Mole (above) and a Non-burrowing animal (below).

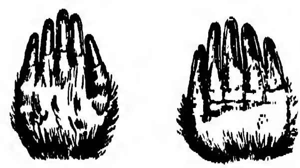


Fig. 744.—Upper and Under Sides of a Mole's Hand

The skeleton exhibits a number of features associated with the burrowing habit, while those parts of the muscular system which are of special use in this connection are extremely well developed. The head has been compared, in shape and mode of action, to a drill or borer, and can be moved forwards and backwards by means of powerful muscles, in relation to which the neck-vertebræ are exceedingly strong, and the long shoulder-blade (scapula) is unusually stout. The tip of the snout ends in a little fibrous shield, covered with horny skin and supported by a piece of gristle, being thus well-fitted for boring

purposes. On a small scale it is not unlike the snout of a pig, which, when used for "rooting" up the ground, plays much the same part. Well-developed collar-bones (clavicles), acting as firm props to the fore-limbs from the inner side, are always associated with marked powers of lateral movement, and to this rule the mole is no exception, for in it these bones are of great relative size and strength. The bones of the fore-limb are short and strong, and the breadth of the supporting framework of the hand gains additional breadth by the presence of a large curved "ploughshare"-bone (fig. 745). Some of the important digging movements of these limbs are effected by powerful muscles which take origin in the breast-bone (sternum), and this is provided with a well-marked ridge or keel that increases the surface for muscular attachment. The same thing is to be observed in the breast-bones of bats and flying birds, where also the breast-muscles are unusually well developed.

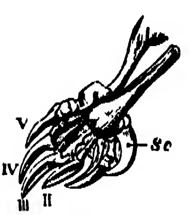


Fig. 745.—Skeleton of Hand of Mole (*Talpa Europæa*; I–V, digits; *Sc*, "ploughshare" bone

The Common Mole and the other species included in the same genus (*Talpa*) are characteristic of the temperate parts of the Old World. Closely related to, and presenting a general agreement with them both in structure and habits, is the Star-nosed Mole (*Condylura cristata*) of eastern North America. In this creature the end of the snout is provided with a conspicuous shield, in the centre of which the nostrils open, and the edge of which is frayed out so as to suggest the popular name (see vol. iii, p. 37).

Much more specialized than the forms just described are the little Golden Moles of South Africa, which constitute a distinct family (*Chrysochloridæ*). The most striking peculiarity is found in the hand, which only possesses the three central digits. As will be seen from the accompanying figure of a common species (*Chrysochloris Capensis*, fig. 746), these are provided with claws of relatively enormous size and strength. These creatures owe their name to the peculiar metallic sheen which their fur presents.

Gnawing Mammals (Rodentia) as Burrowers.—Many of the members of this large and widely-distributed order are more or less distinguished by their burrowing powers, the usual end served being the excavation of dwellings, as in the case of the Rabbit. Some of the most typical burrowers are included in the remark-

able family of Mole-Rats (*Spalacidæ*), of which the included species range widely through Africa and various parts of Asia, while some are native to South-east Europe. Most of them are larger than Moles, to which they present a superficial resemblance, as an outcome of closely similar habits. A typical form is the Common Mole-Rat (*Spalax typhlus*, fig. 747), which inhabits South-east Europe, South-west Asia, and Lower Egypt. Reference to the figure will at once show that the creature is a rodent

Fig. 746.—Cape Golden Mole (*Chrysochloris Capensis*)

and not an insectivore, for the exposed chisel-shaped front teeth characteristic of the order are here clearly visible. The head is rounded, and does not end in a tapering snout like that of a mole, while the tail is more reduced. The thumb is small, but the other four digits of the strong fore-limb bear powerful digging-claws. As in a mole, the velvety fur has no particular "set", and therefore presents no hindrance to either forward or backward movements, in both of which the animal is almost equally expert. The ear-flaps, though not entirely absent as in moles, are extremely small, and the minute eyes are not merely hidden in the fur, but covered over by skin. A review of these characters

shows that this animal is in some respects less specialized than a mole, and in other respects more specialized.

The allied Bamboo-Rats (species of *Rhizomys*) of Central and South Asia, and also native to Abyssinia, are of interest in this connection because they are not quite so much modified in relation to the burrowing habit as the animal last described. In them the eyes, though extremely small, are not covered by skin, while tail and ear-flaps are decidedly less reduced.

The little Sand-Rats (species of *Heterocephalus*) of the North-east African deserts are no larger than mice, entirely devoid of

Fig. 747.—Common Mole-Rat (*Spalax typhlus*)

ear-flaps, but with minute, practically useless eyes. In the burrowing Mammals so far mentioned reduction of friction between the body and the surrounding earth is largely due to the velvety nature of the fur. In this case the same end is attained by the almost complete suppression of the hairy covering. We are here naturally reminded of the sharp contrast between the sleek coat of a seal and the naked skin of a porpoise, arrangements which are both related to diminution of friction with the surrounding medium (see p. 68).

The North American rodents include the family of Pouched-Rats (*Geomyidæ*), of which some members are thorough-going burrowers. Of these perhaps the best known is the Common Gopher (*Geomys bursarius*, fig. 748), a creature resembling a large

rat in some respects, but presenting many of the features which we have seen to be characteristic of burrowers. The short limbs possess the full number of digits, all of which bear strong claws, though these are much better developed on the fore-feet. The fur is velvety and the tail fairly long. Although the ear-flaps are much reduced, the eyes are a good deal larger than is usual

Fig. 748 —Common Gopher (*Geomys bursarius*)

among animals that dwell underground, which suggests that these creatures live to some extent outside their burrows. That closely related animals may differ greatly in appearance, owing to the fact that they have become adapted to widely different habits, is well exemplified by comparing a Gopher with a Kangaroo-Rat, both being members of the same family. The latter form is distinguished by its well-marked leaping powers, and has already been briefly described (see p. 193).

Pouched Mammals (Marsupialia) as Burrowers.—We have

In part of the desert region of South Australia the rôle of ordinary moles is played by a little creature known as the Pouched-Mole (*Notoryctes typhlops*, fig. 749), which has undergone modification along the lines of which so many instances

Fig. 749.—Pouched-Mole (*Notoryctes typhlops*)

have now been given. The head is rounded in front, and bears a firm protective shield of squarish shape. Both pairs of limbs are short and stout, and possess powerful digging claws. Those borne by the third and fourth digits of the hand are of relatively enormous size, and quite throw into the shade all structures of the kind which have so far been described in burrowing forms, the closest parallel being presented by the Golden Moles, where, however, three of the digging claws are especially large (see p. 202). It is characteristic of Marsupials that they should possess a pouch for the reception of the young, which are born in a very immature condition. That the Pouched-Mole is so provided is one of many features which prove that it belongs to this order of Mammals. The pouch is situated in the usual place, far back on the under side of the body, but its opening is posterior, instead of to the front as is usually the case. The short, stumpy tail is covered with very tough skin. There are no ear-flaps, and the small opening of the ear is buried

in the surrounding hair; while the eyes have been reduced much more than in an ordinary mole, being represented by minute black dots imbedded in the skin. The coat is for the most part yellowish-brown in colour, but here and there patches of a golden hue are to be seen. Though soft, it is not distinguished, as in a true Mole, by a dense velvety texture, for the hairs are comparatively long. This is probably explained by the looseness of the sand in which the animal burrows. This is quite unsuitable for the excavation of permanent "runs"; indeed, it falls in immediately, so that there is no necessity for reducing friction during backward movements. Pouched-Moles burrow very near the surface, displaying remarkable energy in the matter.

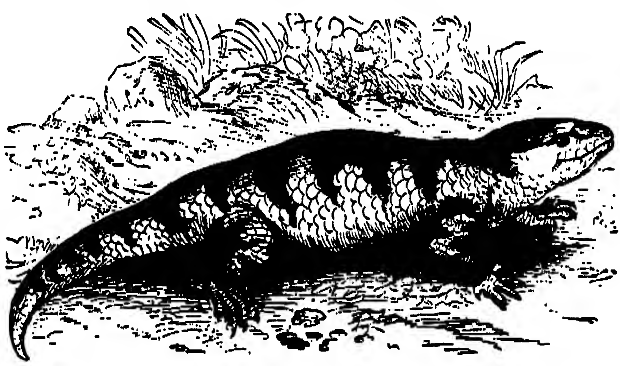


Fig. 750.—Common Skink (*Scincus officinalis*)

REPTILES (REPTILIA) AS BURROWERS.—Many animals of this class are able to burrow more or less, but our special concern here is with animals which live largely or entirely underground. This is the case with some of the Lizards (*Lacertilia*), and also with certain Snakes (*Ophidia*).

Lizards (Lacertilia) as Burrowers.—The family of Skinks (*Scincidæ*) includes a number of forms which burrow with facility, and of which the Common Skink (*Scincus officinalis*, fig. 750) of the desert regions of North Africa may be taken as a type. Although this lizard spends a good deal of its time above-ground, it is greatly specialized in relation to burrowing, its progression through sand being described as so rapid and easy as to suggest a comparison with swimming. The contours of the wedge-shaped snout, flattened from above downwards, pass gradually into those of the head and cylindrical body, and thence on into the short, gradually narrowing tail. The resulting out-

line is not unlike that of a fish, which is not unnatural, as the shapes of both types have been evolved with reference to easy passage through a resistant medium. And the resemblance does not cease here, for the Skink is clothed in closely-fitting armour of overlapping scales, the surface of which is highly polished, and which suggests the scaly investment of such a fish as the Mackerel (see p. 43), except that in the latter the surface is slimy. The last character is in adaptation to the surrounding water, but would not be effective in a desert animal, especially as it would involve too great an expenditure of moisture. That sand may be prevented from getting into the nostrils these are very small, and directed upwards rather than forwards, besides which each opens between two little protective shields. Since a Skink is by no means entirely subterranean in habit, its eyes, though small, are well developed. Injury by sand is prevented by the presence of well-marked eyelids, the lower one having a transparent area or window in its centre, enabling the animal to see pretty well without opening its eyes. The short, stout limbs are provided with strong digging claws, especially in the case of those in front.

For progress through dense vegetation, or for the purpose of burrowing, an elongated, snake-like body offers such advantages that it has been independently evolved in various groups of animals, presenting us with a case of the principle of "convergence" spoken of elsewhere (see p. 193). In plain English this means that close affinity is not necessarily indicated by mere shape and proportions, as these may have resulted from adaptation to the same or similar conditions in members of widely different groups. Internal characters are much more reliable in settling the actual relationship, although these also may be more or less modified as the result of alterations of the outward form.

But assumption of a snake-like form is associated with gradually increasing powers of locomotion by wave-like contractions of the muscular body-wall, in other words by "wriggling". As in the course of evolution along these lines certain animal forms became longer and narrower, they relied more and more on wriggling, and less on progression by limbs. Four legs are only efficient where the body is fairly short. At a certain point in the kind of evolution here considered they become a positive

hindrance, increasing friction and tending to "catch" inconveniently in the surroundings, which were of such a sort as to hamper free progression. We therefore find that the limbs gradually dwindled and ultimately disappeared in the evolutionary series which culminated in snake-shaped forms. A very good case in point is afforded by one peculiar family of thoroughly subterranean lizards which may perhaps be called the Reversible Snake-Lizards (*Amphisbænidæ*), because they progress backwards or forwards with equal or almost equal facility, as their scientific name indicates (Gk. *amphis*, both ways; *bainō*, I move). The majority of these creatures are natives of Africa, the West Indies, and the hotter parts of America, but some of them are native to parts of South Europe and South-west Asia. The skin is much softer than in lizards generally, owing to the absence of scales, except on the head, where they are represented by horny plates.

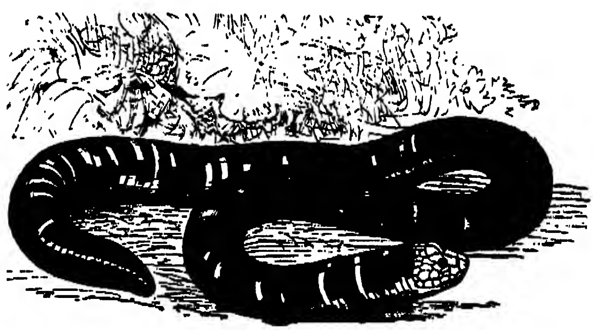


Fig. 751.—Reversible Snake-Lizard (*Amphisbæna fuliginosa*)

Since this region acts as a borer, such a firm investment is clearly necessary, and in connection with this it may be noted that the skull is unusually firm and compact. The eyes are reduced to minute vestiges. Behind the head the soft skin is marked off into a large number of rings. In nearly all cases the limbs are entirely absent, scarcely any trace being left even of the shoulder- and hip-girdles. No less than half the species belong to the type genus Amphisbæna, of which one of the best-known species (*A. fuliginosa*, fig. 751) is a black-and-white creature abundant in South America and the West Indies. It is somewhat less than 2 feet in length.

One much smaller species of these curious worm-like lizards (*Chirotes canaliculatus*) differs from all its allies in the fact that it possesses small fore-limbs, each bearing four clawed digits. It is about 8 inches long, and is a native of California and Mexico.

The Reversible Snake-Lizards wriggle in a worm-like manner,

but the undulations into which the body is thrown are vertical, not horizontal, as is usually the case among elongated animals, *e.g.* Snakes. Bates (in *The Naturalist on the Amazons*) thus speaks of the habits of a South American species of Amphisbæna:—"Those brought to me were generally not much more than a foot in length. They are of cylindrical shape, having, properly speaking, no neck, and the blunt tail, which is only about an inch in length, is of the same shape as the head. This peculiar form, added to their habit of wriggling backwards as well as forwards, has given rise to the fable that they have two heads, one at each extremity. They are extremely sluggish in their motions. . . . The eye is so small as to be scarcely perceptible. They live habitually in the subterranean chambers of the Saüba ant, only coming out of their abodes occasionally in the night-time. The natives call the Amphisbæna the Mother of the Saübas, and believe it to be poisonous, although it is perfectly harmless. It is one of the many curious animals which have become the subject of mythical stories with the natives."

Snakes (*Ophidia*) *as Burrowers.*—There are several snake families of which the members spend the whole or a large part of their time in burrowing. None of these are poisonous, and the small mouth is not capable of being widely opened as in ordinary Snakes, a peculiarity which is in adaptation to their diet of earthworms, insects, and other small creatures, as compared with the relatively large prey which is swallowed by average members of the order. The small head passes without the intervention of a neck into the cylindrical body, which ends in a very short tail. And, as might be anticipated, the scales are very smooth. In an ordinary snake, as we have had occasion to notice (see p. 110), there is a double series of very large scales (ventral shields) on the under side of the body. To these the ribs are firmly attached, and they play a very important part in locomotion. But since the burrowing snakes move in a somewhat worm-like way, instead of being "rib-walkers", there is no need for special ventral shields, and as a matter of fact the scales on the under side of the body are no larger than the others in the forms which are entirely subterranean, and even in those which partly live on the surface of the ground are but little larger. In the latter, useful, though very small, eyes are present, but in the former they have been reduced to useless vestiges.

One of the less-modified families is that of the Cylinder-Snakes (*Ilysiidæ*), which includes but very few species, native to South America, Ceylon, and South-east Asia. One very interesting species, the Coral Cylinder-Snake (*Ilysia scytale*) of tropical South America, is beautifully marked with red and black rings, closely resembling what has elsewhere been described for the poisonous Coral Snakes from the same region (see vol. ii, p. 303.) It is generally considered to be a case of mimicry, the

Fig. 752.—Shield-tailed Snake (*Uropeltis grandis*)

harmless form enjoying comparative immunity from attack owing to its resemblance to its venomous relatives. Cylinder-Snakes have not entirely lost their hind-limbs, for these are represented by a pair of small projections, on each of which there is a claw.

The Shield-tailed Snakes (*Uropeltidæ*) of Ceylon and South India, though seen above-ground during the rainy season, are more thorough-going burrowers than the members of the last family, and consequently exhibit a greater degree of specialization. No traces of the hind-limbs are present, and the ill-developed tail usually looks as if it had been cut off short. Its broad flat end is covered by a firm shield. The short cylin-

drical body is somewhat stiff, and the skull is unusually solid. In suggesting a use for the tail-shield, Gadow (in *The Cambridge Natural History*) says:—"The use of the characteristic tail-shield is not clear; perhaps it assists these rather rigid creatures in digging, by being pressed against the ground". A typical Ceylon species (*Uropeltis grandis*, fig. 752) is of black-and-yellow colour.

The little Blind Snakes (Typhlopidæ) are almost cosmopolitan so far as the warmer parts of the globe are concerned, and live

Fig. 753.—Blind Snake (*Typhlops vermiculatus*). The small drawing represents the head in side view, and shows the vestigial eye as seen by transparency through the shield which covers it

entirely underground. They are more thoroughly adapted to a burrowing life than the members of the two families just described. The front part of the small head is armoured with firm, horny shields, and the vestiges of the eyes are covered by similar shields. The mouth is placed on the under side of the head, and is extremely small. Teeth are present in the upper jaw only. The body is uniformly covered by small round scales, and the tail is very short. One outlying species (*Typhlops vermiculatus*, fig. 753) is native to South-east Europe and South-west Asia. Its tail is tipped with a horny spine.

AMPHIBIANS (AMPHIBIA) AS BURROWERS.—Some of the *Tailed*

Amphibians (*Urodela*) have become eel-like in shape, with accompanying reduction in the limbs, as an adaptation to burrowing in the mud of the ponds which they inhabit. The most notable case is afforded by the Sirens (Sirenidæ), which are found in the

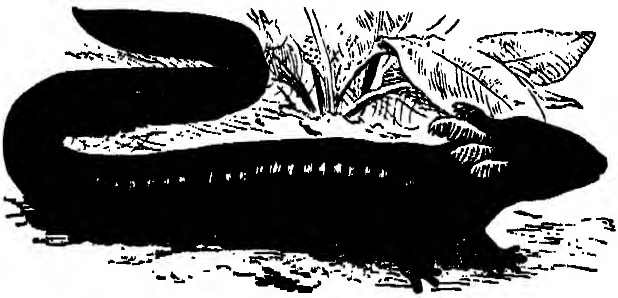


Fig. 754.—Mud-Eel (*Siren lacertina*)

south-east of the United States, and of which the so-called Mud-"Eel" (*Siren lacertina*, fig. 754) is a well-known type. This creature possess no hind-limbs, while the fore-limbs are short and four-fingered. Although a large part of its time is spent in burrowing, it also swims about more or less, and occasionally leaves the water.

The *Limbless Amphibians* or *Cæcilians* (*Gymnophiona*) are snake-like burrowing forms which are more specialized than the Sirens, for they have entirely lost all traces of both pairs of limbs (fig. 755). They are not unlike the Reversible Snake-Lizards in appearance, giving us another case of the phenomenon of "convergence" as the result of adaptation to a particular mode of life. Cæcilians are widely distributed through the hotter parts of the globe.

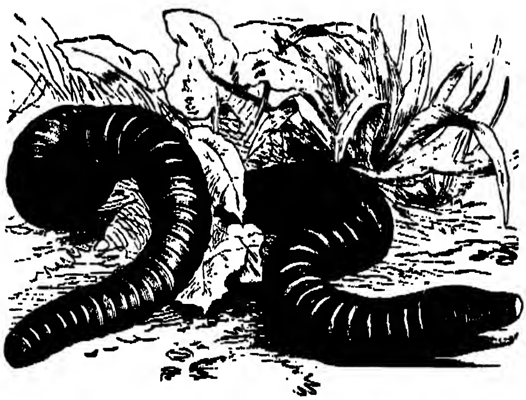


Fig. 755.—A Cæcilian (*Siphonops annulatus*)

The body of one of these creatures presents a series of ring-like markings, and the eyes are mere vestiges, which are either imbedded in the skin or may even be covered by bones belong-

ing to the upper jaw. As in several burrowing animals which have been already described, the skull is very compact and strong, a character which is no doubt related to the use of the head as a boring organ. As in Amphibians generally the skin is soft and slimy, but in most species a large number of little circular calcified scales are imbedded in it. With few exceptions the skin of members of other recent Amphibian groups is devoid of hard parts, although in remote geological ages an order (*Stegocephali*) flourished, of which one important character was the possession of well-developed external plate armour. Despite the peculiarities associated with the burrowing habit, Cæcilians are in many respects a primitive group, and undoubtedly of great antiquity, for it must have taken an immense time for them to get distributed all over the warmer regions of the world. It is therefore not at all improbable that the scales which many of them possess may be inherited from ancestors armoured like the extinct forms just mentioned.

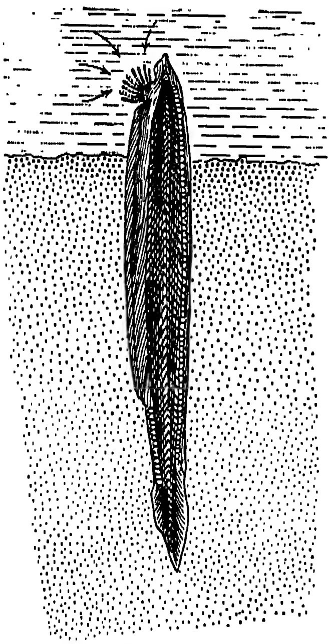


Fig. 756.—Lancelet (*Amphioxus*) Feeding

Fishes (Pisces) as Burrowers.—In the light of our knowledge concerning burrowing Lizards and Amphibians, we naturally turn to eel-shaped fishes for examples of the burrowing habit. The Common Eel (*Anguilla vulgaris*) is a good illustrative case, though only part of its time is occupied in wriggling through the mud, from which it comes out at night to feed. The narrow pointed head is well suited for burrowing, and the external openings of the gill-chambers are narrowed, no doubt for the protection of the gills (see vol. ii, p. 448).

Primitive Vertebrates (Protochordata) as Burrowers.—The Lancelet (*Amphioxus*, fig. 756), with its pointed head and laterally flattened body, is well adapted for making its way through sand with facility. Willey (in *Amphioxus and the Descent of the Vertebrata*) thus speaks of its behaviour in this

respect:—"Amphioxus possesses an extraordinary capacity for burrowing in the sand of the sea-shore or sea-bottom. If an individual be dropped from the hand on to a mound of wet sand which has just been dredged out of the water, it will burrow its way to the lowest depths of the sand-hillock in the twinkling of an eye." The delicate breathing organs are so situated that there is no danger of their sustaining injury from this procedure (see vol. i, p. 295), which is all the more necessary as during feeding the animal lies buried in the sand with only the head end projecting (fig. 756). The pointed front end of the body is supported by the forward extension of an elastic rod (the notochord) which underlies the nerve-chord, and has been aptly described as "the forerunner of a backbone". If the development of any backboned animal is followed, this rod will always be found, though usually partly or entirely squeezed out of existence later on by the appearance of a more serviceable backbone or its equivalent, but except in the Lancelet it never extends further forward than about the middle of the under side of the brain, where it tapers to a point. It is therefore regarded as probable that this structure has grown forwards to the extreme front end of the body in this animal, so as to make it sufficiently firm for burrowing purposes.

Fig. 757.—Acorn-headed Worm (*Balanoglossus*)

The Acorn-headed Worm (*Balanoglossus*) (fig. 757) is also a burrower, and its almost cylindrical worm-like body is well-suited to its habits. But here the chief agent would appear to be the curious acorn-shaped projection, usually called the "proboscis", which is attached by a comparatively narrow stalk to its front end. Blood can be squeezed into this organ so as greatly to lengthen it. By muscular contraction it is then made shorter, and the body is thus dragged up to it. No doubt assistance is

also given by the layer of longitudinal muscle-fibres in the body-wall, by contraction of which the body can be shortened. The narrow stalk of the proboscis would be a source of weakness were it not that a support is afforded by a short elastic rod, which is developed as a forward growth from the digestive tube, and is usually regarded as representing the elastic notochord of the Lancelet, though it extends neither far forwards nor far backwards.

CHAPTER XLIX

MUSCULAR LOCOMOTION—BACKBONELESS ANIMALS (INVERTEBRATA) AS BURROWERS

Typical burrowers are found among the Molluscs (Mollusca), Jointed-Legged Animals (Arthropoda), Bristle-Worms (Chæto-poda), Siphon-Worms (Gephyrea), and Hedgehog-skinned Animals (Echinodermata). There are also parasitic animals belonging to various groups, which burrow within the bodies of other organisms, but these are best dealt with later on when Parasitism is being considered.

MOLLUSCS (MOLLUSCA) AS BURROWERS.—Animals of this kind are found among Snails and Slugs (Gastropoda) and Primitive Molluscs (Protomollusca), while the burrowing habit is eminently characteristic of Bivalve Molluscs (Lamellibranchia) and Tusk-Shells (Scaphopoda).

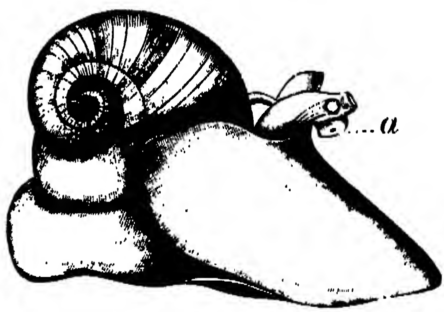


Fig. 758.—Burrowing Sea-Snail (*Natica Josephina*); *a*, boring organ

Snails and Slugs (Gastropoda) as Burrowers.—Some marine Snails burrow in sand or mud in pursuit of food, and are specialized in structure so as to fit them for this mode of life. This is clearly necessary, for the shape of an ordinary crawling form is in several ways unsuited for progression through sand and the like, as will at once be realized by recalling the configuration of an ordinary snail. Not only is the front end of the body quite different from what is required for such a purpose, but the head with its delicate sense organs would be liable to injury. Besides which the prominent rounded shell with its contents would be a great hindrance to progression. Reference to fig. 758 will show how

these various difficulties have been got over in one typical burrowing Sea-Snail (*Natica Josephina*). The shell is not nearly so prominent as in an ordinary crawling form, and its surface is exceedingly smooth, so as to reduce friction with the surrounding sand. By modification of the front part of the foot (fore-foot) the head is protected, and at the same time a sort of burrowing wedge is produced in the following way:—The fore-foot is very large, and marked off transversely behind. Part of it is in the form of a muscular flap which can be folded back against the head, thus affording adequate protection, and at the same time giving a wedge-like outline. The manner in which this animal feeds has elsewhere been described (see vol. ii, p. 98).

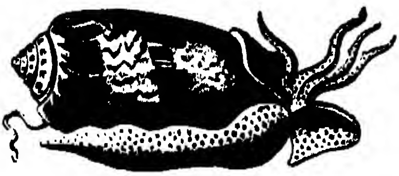


Fig. 759.—Olive-Shell (*Oliva*)

The same sort of modification as that of which an account has just been given is found among the Olive-Shells (Olividæ, fig. 759). As will be seen by reference to the figure, the fore-foot is clearly marked off, and is crescent-shaped. It can be folded back against the head in the same way and for the same purpose as in a Natica.

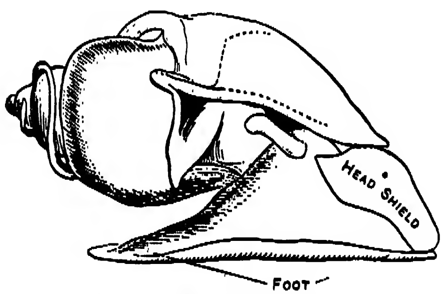


Fig. 760.—Actæon, showing head-shield, the black dot on which represents the vestigial eye

A good many of the relatives of the Sea-Hares burrow in the sand, but here the necessary adaptation is of quite a different nature. In Actæon, for example (fig. 760), only the under side of the burrowing organ is made up of the front part of the foot, as it is mainly constituted by a modification of the head in front, to which the name of head-shield is applied. In a Sea-Hare (*Aplysia*, see p. 35) the head bears two pairs of feelers or tentacles. The eyes are placed at the bases of the front ones. It is thought that the head-shield has been formed by enlargement and fusion of the anterior tentacles, a view which is supported by the fact that a pair of vestigial eyes are to be seen on the front of the shield. The reduction of the organs of sight to mere useless vestiges is a phenomenon

of which we have already found a number of illustrations among backboned animals which burrow.

Bivalve Molluscs (Lamellibranchia) as Burrowers.—The large majority of bivalves live in sand or mud, through which they make their way by means of their foot, which is modified accordingly. We have seen that the foot of a Snail is a fleshy projection on the under side of the body, possessing a flat, sole-like surface on which the animal creeps (see p. 104). The same thing is more or less true for a small number of primitive bivalves, and for still fewer of those which are much specialized as to the structure of their gills and in other ways. But in a fairly average form (fig. 761) the foot is placed rather to the front, flattened from

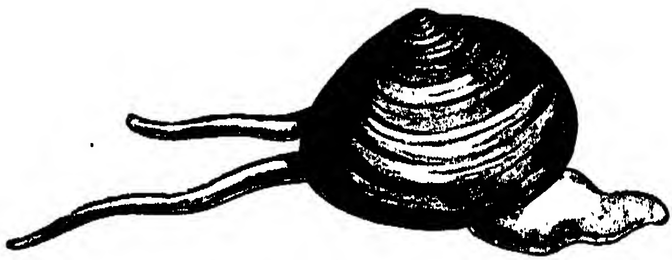


Fig. 761.—Burrowing Bivalve (*Scrobicularia*). Protruded foot on right, and extended siphons on left

side to side, and shaped like a ploughshare or axe-head. At the back in typical burrowers are to be seen a pair of tubes or siphons (see figure), not infrequently united together, but in either case playing an important part in feeding, breathing, and removal of waste (see vol. ii, p. 249). Without any previous knowledge of the way in which the foot is used we should probably imagine that it pushed against the mud or sand in front, thus causing the animal to progress backwards. This, however, is not the case. It is extended forwards between the two valves of the shell, being at the same time considerably enlarged by the pumping of blood into it. It is then shortened by contraction of the muscle of which it is mostly made up, and the blood is driven back into the body. The result is, that the animal is drawn forwards, and by continued repetition of the process is able to get along with a speed which varies greatly in different cases.

We have noticed that in some of the greatly specialized burrowers among Lizards and Amphibians the body has become long, and narrow, thus facilitating progress through earth and the like.

Evolution along somewhat similar lines has taken place among those bivalves which are most notable for their burrowing powers. A step in this direction has been taken, for instance, in the Sand-Gaper (*Mya arenaria*, fig. 762), and a still further modification in the same direction in the Razor-Shell (*Solen*, fig. 763). It is also clear that as the foot is the burrowing organ, its most effective position is far forwards, and the way in which it has gradually been shifted to the front is well seen in the same two figures. The foot of a Razor-Shell is of remarkable length when extended, and its end then forms a sort of swollen knob, which holds firmly to the sides of the burrow during the shortening process by which the animal is drawn onwards. So rapidly can these creatures retreat, when alarmed, that their capture is a matter of considerable difficulty, but is rendered somewhat easier by the fact that they burrow obliquely when adult. It is only the small immature individuals which descend into the sand vertically, or nearly so, and this greatly increases their chances of escape from enemies, so that more of them become full grown than would otherwise be the case.

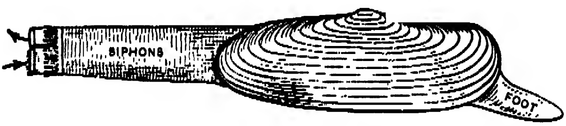


Fig. 762.—Sand-Gaper (*Mya arenaria*), showing foot and siphons


Fig. 763.—Razor-Shell (*Solen*), showing foot on left and siphons on right

In these burrowing forms, when the foot is very large, the two valves of the shell cannot be brought together in front, *i.e.* they "gape". And when the siphons are well-developed the shell gapes behind as well. An obvious advantage is thereby gained, for the animal can move, feed, and breathe without separating the two valves from one another, an operation which would not only take time, but also lead to unwelcome sand or mud getting in between them. But this is also prevented by another kind of modification. In, say, a Freshwater Mussel, which has no siphons, and is not a rapid burrower, the two mantle-flaps, that invest the body right and left like the flaps of a coat, are almost entirely free from one another, so that they can easily be turned back, without cutting anything, when the shell is removed. But in many forms which burrow in sand

they are not only fused together and drawn out into siphons at the back, but are also more or less united together below, except at the place where the foot is protruded (fig. 764).

Some bivalves can burrow in rock or wood, as, for example, the Piddock (*Pholas dactylus*) (vol. i, p. 336), which tunnels in

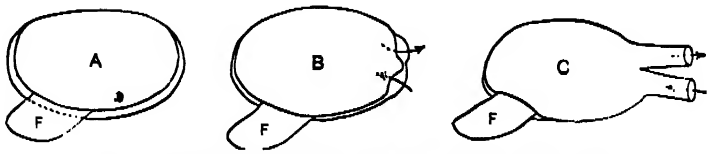


Fig. 764.—Bivalves in Side-view to show stages in Fusion of Mantle-lobes

F, foot; arrows represent water-currents entering and leaving mantle-cavity. In A there is no fusion, in B a small amount of union at back, with incipient siphons. C shows a large amount of fusion both at back, where well-developed siphons are present, and also below.

limestone, or even in siliceous matter. The shell gapes at both ends, in relation to the presence of a strong rounded foot and well-developed siphons. The front part of it is covered with transverse rows of short, strong spines, and the animal is able to twist itself round so as to use these after the fashion of a rasp. It is sometimes erroneously stated that the cylindrical foot is the chief excavating agent.

Since Piddocks and certain other bivalves bore in hard substances for the sake of securing sheltered homes, their operations in this direction are more naturally treated with relation to the subject of Animal Dwellings, and further details will be given when this is dealt with in a later section.

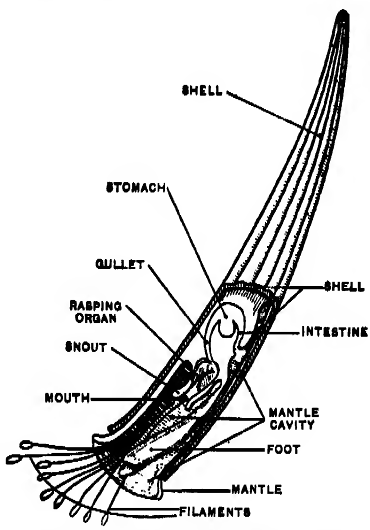


Fig 765.—Tusk-Shell (*Dentalium*). The shell is partly removed

Tusk-Shells (Scaphopoda) as Burrowers.—These are widely-distributed marine animals of typically burrowing habit. The elongated, gradually-tapering, conical body (fig. 765) is well-adapted for progression through sand, and the smooth shell of corresponding shape by which it is invested greatly reduces friction. The burrowing organ is the three-lobed foot, which can be protruded from the broad end of

the shell, and is used like the corresponding part of a bivalve. There are neither eyes nor tentacles.

Primitive Molluscs (Protomollusca) as Burrowers.—Most of the members of this small group are only known to professional zoologists, and very few facts have been determined as to their habits. Some of them are of cylindrical form, as, for instance, *Chætoderma* (fig. 766), a small, worm-like animal, which has probably acquired its shape as a result of burrowing in mud. In this particular case there is absolutely no trace of the muscular foot, which, as we have seen, is the characteristic locomotor organ of molluscs, but a sufficient number of the other structures by which the members of that group are distinguished are here present to make us feel pretty certain we are actually dealing with a specialized mollusc. Chætoderma presumably wriggles through mud, worm-fashion, by means of the muscular body-wall, and the numerous spicules with which the skin is studded must prevent it from slipping back.

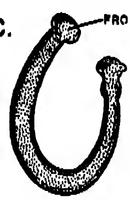


Fig. 766.—Chætoderma

Jointed-limbed Animals (Arthropoda) as Burrowers.—Typical burrowing animals are found in the following classes:—Insects (*Insecta*), Centipedes and Millipedes (*Myriapoda*), and Crustaceans (*Crustacea*).

Insects (Insecta) as Burrowers.—One of the most thoroughly subterranean insects is the Mole-Cricket (*Gryllotalpa vulgaris*) (fig. 767); which tunnels extensively in the ground. The front legs are the burrowing organs, and are remarkably specialized. They are exceedingly strong and broad, and their end-parts, the feet or tarsi, which in average insects are quite slender, several-jointed structures, look almost like the hands of a mole. This, coupled with the habits, accounts for the popular name. The digging part of the foot is mainly formed by the great enlargement of the uppermost joint, which comes next the shin or tibia. It is provided with four strong pointed projections. A Mole-Cricket in the course of its excavating work must frequently encounter roots, which cannot simply be burrowed through in the same way as the earth. To meet this exigency some of the end joints of the foot are provided with cutting projections, placed outside of the toothed spade, as will be seen by reference to the figure. The foot can be bent back against

the shin, so as to work these against other sharp projections borne upon that region as well, and a pair of shears or scissors is thus constituted by which the roots are easily cut through.

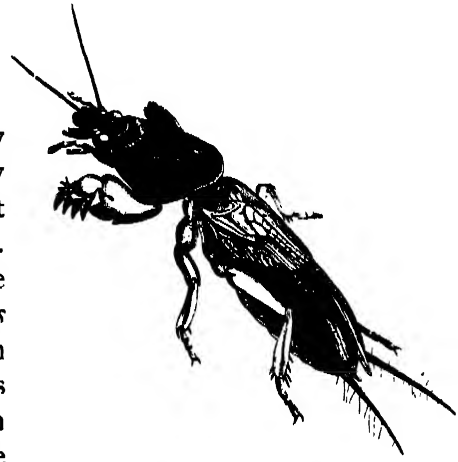


Fig. 767.—Mole-Cricket (*Gryllotalpa vulgaris*)

Some of the White Ants or Termites live in hollow trees, and bite out galleries by means of theis powerful first pair of jaws, or mandibles. The curious little Book-Louse or Book-"Worm" (*Atropos divinatoria*, fig. 768), which belongs to a related family, is notorious for the way in which it drives tunnels through the leaves of books. Soft and weak as to its body, the hard-tipped mandibles of this creature are nevertheless strong enough to bite through paper, and each of the second pair of jaws (first maxillæ) bears a narrow pointed projection or "pick", which appears to help in this destructive operation. This insect and one of its equally small allies are sometimes known as the "lesser death-watches", because to one or both of them are possibly due some, at least, of the persistent tickings which rouse apprehensions in the minds of the superstitious.

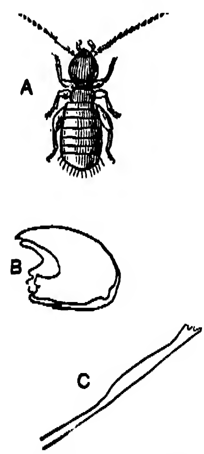


Fig. 768.—Book-Louse or Lesser Death-Watch (*Atropos divinatoria*)

A, much enlarged; B, mandible; and C, "pick" of second jaw, still further enlarged.

A large number of insects spend the early part of their existence burrowing in the ground, boring in wood, mining in leaves, or excavating articles of food, while others begin life as wriggling mud-dwellers.

The exigencies of space only permit mention of a few of the more interesting of these. Many instances of the sort are to be found among Beetles. Wood, for example, becomes "worm-eaten" owing to the ravages of the grubs of the "greater death-watches" (*Anobium striatum* and *A. tessellatum*), and the adult beetles are undoubtedly responsible for some of the ticking

noises which have often been supposed to portend disaster. So far from this, however, the sound is really a love-call, which the insect produces by striking its hard head against the wood. It is said that apparently-worm-eaten, spuriously-antique furniture is manufactured by the simple device of firing small shot at the objects to which a deceptive appearance of age is to be given. So-called "weevilly" biscuit, which has stirred the discontent of many generations of sailors, owes its unpleasant condition to the grubs of a beetle related to the death-watches (*Anobium paniceum*).

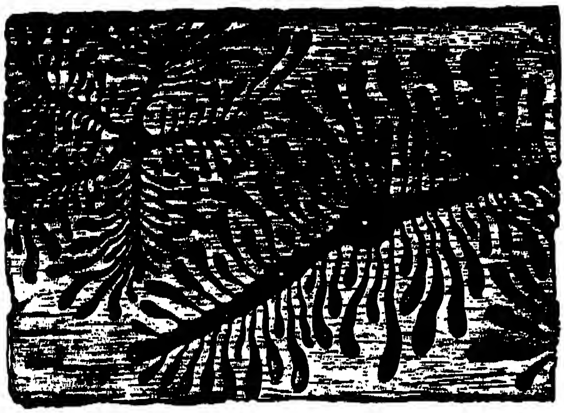


Fig. 769.—Galleries of a boring Beetle-Grub (*Bostrichus typographus*)

The greater part of the life of the Common Cockchafer (*Melolontha vulgaris*) is spent underground, where its grubs burrow in the earth and feed on the roots of plants. This subterranean life lasts from three to five years. The grubs of the little Click-Beetles or Skip-jacks (*Elateridæ*) are the notorious "wire-worms", which gnaw the roots of crops. The Weevils (*Curculionidæ*) include some 20,000 species, of which the legless grubs bore in a great variety of plants, the kind and parts attacked varying in different sorts of these small insects. The wood of many trees is infested by the grubs of different beetles, and the borings are often very elaborate, and arranged in a way characteristic of the species. The galleries made by one of them (*Bostrichus typographus*) are shown in fig. 769.

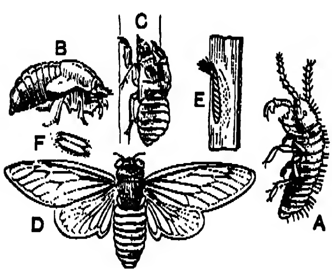


Fig. 770.—Seventeen-year Cicada (*Cicada septendecim*). Reduced to ½, except F, which is slightly magnified

A, larva; B, nymph; C, skin of nymph from which perfect insect D has emerged; E, batch of eggs; F, two eggs enlarged.

The larvæ of some of the Plant-Bugs are notable burrowers,

among which perhaps the most remarkable is the Seventeen-year Cicada (fig. 770), which during its subterranean life feeds upon roots. Regarding it, Sharp (in *The Cambridge Natural History*) speaks as follows:—"The North American *Cicada septendecim* is a most notorious insect owing to its life-cycle of seventeen years. It is considered that the individual, after nearly seventeen years of underground existence, comes to the surface and leads for a brief period the life of a noisy Insect. This is the only insect at present known having so considerable longevity. This fact, and several other peculiarities, have attracted much attention. . . . It is very difficult to obtain information as to their strange, prolonged, subterranean life; it is said that the insects sometimes penetrate to a great depth—10 feet, even 20 feet, are mentioned—and as great changes may take place on the surface during their long lives, these insect Rip Van Winkles sometimes emerge in very strange conditions, and may appear even in deep cellars."

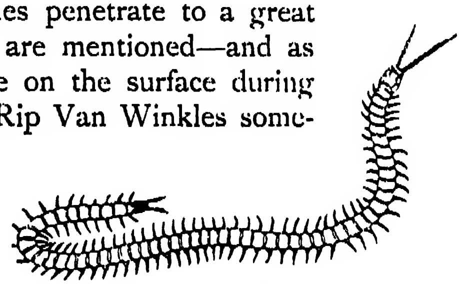


Fig. 771.—Earth-Centipede (*Geophilus*)

Centipedes and Millipedes (Myriapoda) as Burrowers.—The Earth-Centipedes (*Geophilidæ*, fig. 771) are widely-distributed, slender creatures, devoid of eyes, no doubt as an adaptation to their subterranean habits. They feed on earth-worms for the most part, and burrow in the ground in pursuit of their prey, a procedure which is no doubt facilitated by the narrow tunnels which the worms themselves make.

The little creatures known as Snake-Millipedes (species of *Julus*), the slender form of which is indicated by their name, are commonly found in soil, and are believed to injure the roots of crops. They are often called "false wire-worms".

Crustaceans (Crustacea) as Burrowers.—Many of the members of this class are able to excavate temporary or permanent burrows as homes or refuges, and a small number of them tunnel the submerged parts of wooden piles and the like. One such form (*Chelura terebrans*) is related to the Sand-Hoppers, but its body, instead of being flattened from side to side, is cylindrical, which is a more suitable shape for burrowing purposes. Associated with this is often found the Gribble (*Limnoria lignorum*), a

relative of the Slaters and Wood-Lice. The burrows are bitten out in both instances, and the wood used as food.

BRISTLE-WORMS (CHÆTOPODA) AS BURROWERS.—Many of the marine members of this group burrow in sand or mud, by wriggling movements due to the contraction of the layers of muscle in the wall of the body. The hollow, conical foot-stumps (see p. 98) with the bristles imbedded in them are also of use for the same purpose, provided the sand or mud is of fairly loose texture. Such projections, however, if well-developed, greatly increase the friction, and we must regard them as organs which have been primarily evolved in the interests of crawling upon firm surfaces. In some of the best burrowers, such as the Lug-Worm (*Arenicola piscatorum*, fig. 772), they have been reduced to insignificant dimensions, so that the bristles are practically borne upon the main body-wall, and at the same time such burrowing forms have become cylindrical, the advantage of which is obvious. A great many of these animals swallow mud or sand for the sake of the nutritious matter therein contained, and they may therefore be said to eat their way through the deposits in which they are found, as well as to wriggle through them. The twisted heaps of material which are often seen on mud or sand are "castings" which have passed through the bodies of such creatures, and it is thought that the variously coloured muds which make up extensive deposits near the edge of the land in many places have, to a very large extent, been subjected to the swallowing process by marine worms and other creatures of similar habit. It may also be noted that the head region of the Lug-Worm is pointed, and devoid of the eyes and feelers which are characteristic features of free-living forms such as the Sea-Centipede (*Nereis*). The boring shape and reduction of sense organs liable to injury are strongly reminiscent of similar

Fig. 772.—Lug-Worm (*Arenicola piscatorum*)

adaptations presented by moles and other burrowing Vertebrates.

The marine Bristle-Worms, in average cases, are distinguished by the possession of well-developed foot-stumps, in which many bristles are embedded, on which account they have been termed Many-Bristled Worms (*Polychæta*). We have seen, however, that the foot-stumps may be greatly reduced to facilitate burrowing, and it may be added that in these cases the bristles are also less numerous, and may be comparatively short. Such reductions enable us to understand the condition of freshwater and terrestrial forms, in which the foot-stumps have altogether gone, while the bristles are comparatively few in number. Hence these forms

Fig. 773.—Earth-Worms

are grouped together as Few-bristled Worms (*Oligochæta*). The head-region is pointed and devoid of tentacles, in most cases also of eyes as well. The freshwater forms are of delicate texture, and their bristles are more numerous and often longer and more complex in form than those of the earth-worms. This is easy to understand when we reflect that some of them do not burrow at all, while those that do only have to wriggle through soft mud which presents but little hindrance to their passage.

Earth-Worms (fig. 773) are the most specialized burrowers of all Bristle-Worms, and are able to make their way with ease through stiff soil as well as through that of looser texture. The body is pretty nearly cylindrical for most of its length, though in some species the hinder end is flattened from above downwards. It is clearly divided by transverse grooves into a large number of rings or segments. Nearly every one of these has bristles imbedded in it, there being in some earth-worms (*Perichæta*) a considerable number of them projecting at regular

intervals all the way round the segment. But in the ordinary kinds of worm (species of *Lumbricus* and *Allolobophora*) to be obtained by digging in this country there are only eight bristles per segment. Except in very large specimens these can hardly be seen without the aid of a lens, as they are very short, and only their tips project to the exterior. But they are easily felt by passing the worm backwards between finger and thumb. The arrangement of the bristles is characteristic. Two double lines of them can be made out on either side of the body, placed rather nearer the under than the upper surface. A foot-stump of an ordinary marine worm is divided into an upper and

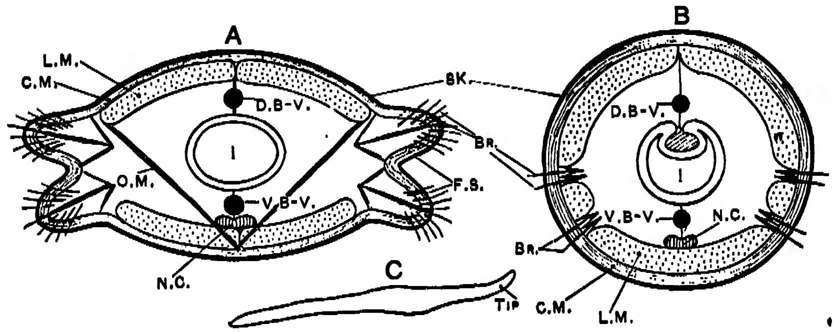


Fig. 774.—Diagrammatic Cross-sections through Marine Bristle-Worm (A) and Earth-Worm (B)

SK, skin; C.M., circular muscle; L.M., longitudinal muscle; O.M., oblique muscle; F.S., foot-stump; BR, bristles; I, intestine; D.B-V., dorsal blood-vessel; V.B-V., ventral blood-vessel; N.C., nerve-cord. C, bristle of Earth-Worm, greatly enlarged.

lower part, each bearing numerous bristles. If we suppose these to get smaller and smaller, and at the same time the number of bristles to be greatly reduced, the arrangement as seen in the earth-worm would ultimately be reached (fig. 774).

An earth-worm bores into the soil by means of the layers of muscles in the body-wall, in much the same way as it crawls. Under the skin is a circular layer, in which the fibres run transversely, and inside this is a longitudinal layer, of which the fibres are parallel to the long axis of the body. It is clear that the shortening or contraction of the fibres of the circular coat will make the body longer and at the same time narrower, while the contraction of the longitudinal fibres will have the opposite effect. The bristles serve as "hold-fasts", preventing the animal from slipping back, and their ∫-shaped form gives them a very firm hold on the soil, while under ordinary circumstances their

points are directed backwards, hence the rough feel of a worm passed the wrong way between the fingers. Suppose, now, that the front part of a worm is elongated, and forced forwards into the soil by contraction of the layer of circular muscle, a sufficient number of the bristles at the head end then grip the earth firmly, and the rest of the worm is dragged forwards by contraction of the longitudinal muscles. A little ground is thus gained, and by continuing the process gradual onward progression is brought about. Earth-Worms are only to be found where the soil contains a certain amount of moisture, for they breathe by the general surface of the body, a process which is dependent upon the skin being kept damp (see vol. ii, p. 444). This moisture also reduces friction, thus facilitating burrowing, and the same end is attained by the slimy nature of the skin.

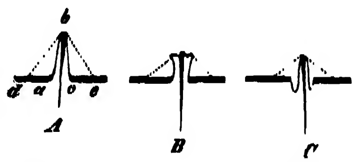


Fig. 775.—Diagram to explain Movement of Earth-Worm Bristles

A, bristle contained in pouch *a b c*; *d b*, *e b*, muscle-fibres. B and C, bristles protruded to varying extents.

These worms are able to move backwards as well as forwards in their burrows, which would scarcely be possible if the bristles were always projecting back. This, however, is by no means the case. Each bristle is provided with a special series of muscle-fibres, which take origin in the body-wall and converge to its imbedded end. The bristle is, so to speak, placed within a hollow cone, of which the side is composed of a series of such fibres. The arrangement is shown diagrammatically in section in fig. 775, and of course only two of the fibres can be indicated. If the one on the right shortens, the tip of the bristle will obviously move to the left, or to the right if shortening takes place in the fibre on the left. And if all the fibres making up the wall of the cone were to successively shorten, each relaxing immediately afterwards, the tip of the bristle would be moved round in a small circle. In fact there are appropriate muscle-fibres for moving the bristle in any required direction. If all the fibres contract together the bristle is protruded as shown in the figure,

As earth-worms continually swallow earth for the sake of the nutriment which it contains, they may also be said to eat their way through the ground, as some of the marine worms similarly facilitate their progress through sand or mud. These creatures

continually bring up earth from below and deposit it on the surface in the form of "castings", and Darwin's observations on the subject led him to the conclusion that a large proportion of the soil of this country must have passed again and again through the bodies of worms.

SIPHON-WORMS (GEPHYREA) AS BURROWERS.—A great many of these burrow in the sand and mud of the sea-floor, continually swallowing these substances in much the same way and for the same reason that earth-worms swallow earth. The most typical cases are afforded by the common Siphon-Worms (species of *Sipunculus*, fig. 776), which at first sight might almost be mistaken for earth-worms, though closer examination shows that their bodies are not divided into segments, and bristles are altogether absent. The muscular body-wall effects onward progression much in the same way as in worms which burrow in the soil.

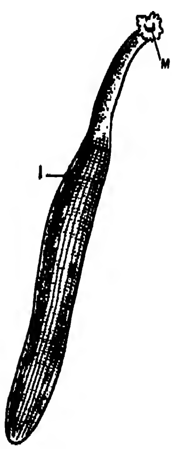


Fig. 776.—Common Siphon-Worm (*Sipunculus*); M, mouth; I, intestinal aperture

HEDGEHOG-SKINNED ANIMALS (ECHINODERMATA) AS BURROWERS.—The Sea-Cucumbers (*Holothuroidea*) swallow sand and mud, in which some of them are able to burrow like worms. As might be anticipated, those of them which are most markedly cylindrical are best adapted to this mode of life. One such form (*Synapta*) has already been described in relation to creeping, and the arrangements by which this is brought about are equally suitable for effecting progression through mud, &c. (see p. 97). Indeed this particular Sea-Cucumber is more notable as a burrower than as a creeper.

CHAPTER L

MUSCULAR LOCOMOTION OF ANIMALS—CLIMBING

We have elsewhere seen (p. 87) how difficult it is to sharply distinguish between Creeping and Climbing. The latter kind of progression involves fixing the front part of the body to some firm object or surface, the animal being then drawn forwards to the place thus affording a hold. In ordinary language climbing also means progression in a more or less upward direction by means of this pulling process. But as the lower animals devoid of jointed limbs pull themselves along in this way irrespective of the inclination of the surface traversed, we have found it convenient in their case to use the word "creeping" throughout. The sections on Walking, Running, &c., have been somewhat arbitrarily concerned with those forms only in which jointed limbs are present, *e.g.* Insects, Spiders, Crustaceans, and Land Vertebrates. And the present section on Climbing will be similarly restricted to the consideration of one particular variety of locomotion in the same set of forms.

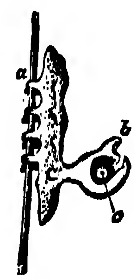


Fig. 777.—Amœba climbing up a Stem, *a*; *b*, projection of body enclosing a mass of food, *c*

It may be well, however, to briefly describe a few cases of creeping up inclined surfaces by lower animals, as many naturalists would unhesitatingly use the word "climbing" in describing such movements.

Although the little Proteus Animalcule (*Amœba*) is a mere speck of protoplasm, quite devoid of any parts which can be called muscular, it has sometimes been observed creeping up the stems of water-plants in a way which strongly suggests climbing. This is very well shown in fig. 777, taken from a drawing by Professor Mœbius. Four pairs of blunt lobes (pseudopods) of the body have been protruded, to be successively used as the means of pulling the animal up a vertical stem.

In fig. 778 are represented in a diagrammatic way the manœuvres of a Star-Fish which has been placed on its back at the bottom of a small glass aquarium. The tube-feet are successively extended, fixed to the vertical glass side, and shortened, so that in the end the animal is brought into a vertical position. By loosening the uppermost feet, stretching them up, attaching them to the glass, and then shortening them, the feet next below following suit, and so on, the animal is able to progress vertically upwards.

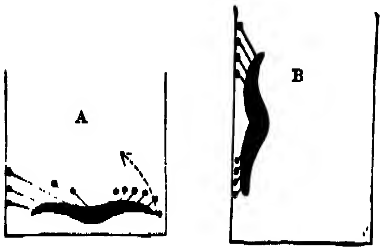


Fig. 778.—Diagram of Star-Fish Movements; in A the animal is beginning to right itself, and in B is climbing up vertical surface. See text

Another example is afforded by a small freshwater bivalve (*Cyclas*) which is able to make its way up the vertical side of an aquarium. The means employed are indicated in fig. 779. The first outline (A) shows the muscular foot stretched upwards to its fullest extent and holding firmly to the glass by its tip (*a*). This organ is then shortened, so that the animal is dragged up a little way (B), when it fixes itself by the hind part of the foot (*b*), used sucker-fashion. The foot is then stretched up again (*c*) and once more attached, and so on. Graber has calculated that in warm weather, which is favourable to activity, it will take a large individual about twenty minutes to creep up the side of a tumbler of water in which it has been placed.

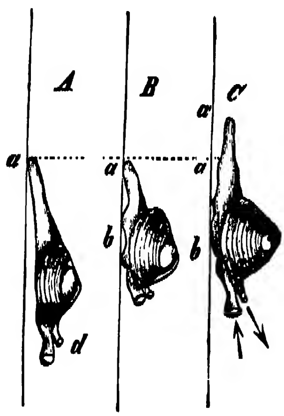


Fig. 779.—Bivalve (*Cyclas*) Climbing. Described in text

We now pass on to the consideration of Climbing in the narrower sense, as exhibited by animals which possess jointed limbs, beginning with Backboned Animals (Vertebrates), and then considering a selection of Backboneless Animals (Invertebrates).

BACKBONED ANIMALS (VERTEBRATA) AS CLIMBERS

Typical climbing animals are found among Mammals (Mammalia), Birds (Aves), Reptiles (Reptilia), Amphibians (Amphibia), and Fishes (Pisces).

MAMMALS (MAMMALIA) AS CLIMBERS.—We have here a large choice of examples, and it will only be possible to review a few of the most instructive cases, beginning with the highest order, most members of which are distinguished by their climbing powers.

Man and Monkeys (Primates) as Climbers.—The great majority of Apes and Monkeys are essentially forest animals, and many points of their structure are the result of adaptation to climbing among trees. Some of the chief principles involved in this sort of progression will be understood by reference to fig. 780, which may be taken to represent a Man or a Monkey climbing a pole. The upper limbs in A have been extended to grasp the pole above the head, while the strongly-bent lower limbs also grip it firmly. The next step is indicated in B, where the upper limbs have been bent so as to *pull* the body up, and the lower limbs straightened for the purpose of *pushing* it up. The dotted lines in A represent very diagrammatically the muscles which, by their contraction, bend the former and straighten the latter.

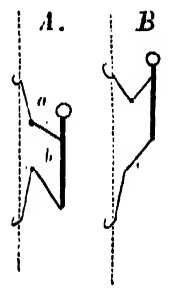


Fig. 780.—Diagram of a Man climbing a Pole, showing successive stages A and B: *a* and *b*, muscles which bend arm and straighten leg

In order that this kind of progression may take place rapidly and safely, it is clearly necessary that the limbs should terminate in efficient grasping organs. Monkeys are very well off in this respect, and were formerly termed the "Four-handed" Mammals (Quadrumana) in reference to the fact, for in ordinary language a "hand" means an extremity with well-marked clasping powers, and in this sense the feet of a Monkey may almost have the word applied to them. In an average Old World Monkey the hand is adapted for holding on to small branches and the like by a modification of the thumb-joint of precisely the same kind as that existing in a human being (see vol. i, p. 31). Examine your own hand and you will see that the projecting part of this

digit is supported by two bones, while there are three such in each finger. The palm of the hand possesses five bones, the bases of which are jointed on to the wrist, but the joint between the palm-bone of the thumb and the wrist is of different character from the rest, for the surfaces of contact are saddle-shaped, an arrangement which permits of great freedom of movement. By means of a special muscle the thumb can be moved at this joint so as to be brought across the palm opposite to the fingers, and anything between it and them can thus be firmly gripped. In other words, the thumb is opposable. Examination of an Old World Monkey's foot shows that a similar modification exists there as well, for the great toe is opposable, and we also note that the toes are comparatively long, while the soles of the feet are inclined inwards. The human foot possesses entirely different proportions, since it has been greatly modified for the firm support of the body during walking (see vol. i, p. 32). All the toes are relatively short, and the great toe is not opposable. A Monkey therefore is able to hold on to trees by means of its feet alone in a way that would be quite impossible for a human being. This is very admirably shown in fig. 781, taken from an instantaneous photograph of a Pig-tailed Monkey (*Macacus nemestrinus*), native to South-east Asia.

It is perhaps only fair to remark that the contrast between the foot of a typical Monkey and that of an adult European is considerably emphasized owing to the unnatural cramping the latter has commonly undergone in badly-fitting foot-gear. The feet of savages are much more mobile, and are often used for purposes that would be quite out of the question with our own half-crippled extremities. And the feet of very young babies will well repay a careful examination. The toes here show remarkable freedom of movement, the soles are inclined inwards like those of a Monkey, and a number of creases are present which closely resemble those to be found in the inferior Mammal. We further note that the legs are not of disproportionate length as in the adult, while the strength of the hand-grip is extraordinary. Romanes (in *Darwin and after Darwin*) writes as follows regarding the last character:—" Dr. Louis Robinson has recently observed that the grasping power of the whole human hand is so surprisingly great at birth, and during the first few weeks of infancy, as to be far in excess of present requirements on the

Fig. 781.—Pig-tailed Monkey (*Macacus nemestrinus*), showing grasping feet

part of a young child. Hence he concludes that it refers us to our quadrumanous ancestry—the young of anthropoid apes being endowed with similar powers of grasping in order to hold on to the hair of the mother when she is using her arms for the purposes of locomotion. This inference appears to me justifiable, inasmuch as no other explanation can be given of the comparatively inordinate muscular force of an infant's grip. For experiments showed that very young babies are able to support their own weight by holding on to a horizontal bar for a period varying from one-half to more than two minutes." Enthusiasts are recommended to discreetly conceal their real motives when endeavouring to verify the foregoing facts by examination of very young specimens of the human species.

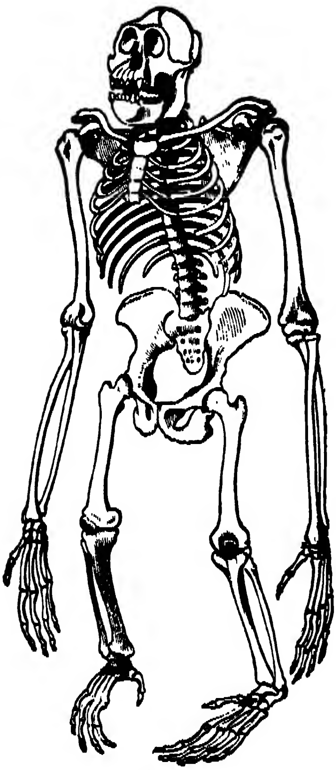


Fig. 78a.—Skeleton of a Gorilla

It is difficult to resist the conclusion that our remote ancestors were expert climbers of arboreal habit. The fact that drowning persons invariably throw their arms out of the water has by some been referred to an instinctive attempt to attain safety by an endeavour to grasp as it were at the branches of the original tree dwelling. But this is extremely doubtful. Most readers will remember that Bret Harte has immortalized the grasping power of the infant hand in *The Luck of Roaring Camp*, and Robert Louis Stevenson has happily touched off the subject of our arboreal ancestry in the following passage (from *Memories and Portraits*):—"There is a certain critic, not indeed of execution but of matter, whom I dare be known to set before the best: a certain low-browed, hairy gentleman, at first a percher in the fork of trees, next (as they relate) a dweller in caves, and whom I think I see squatting in cave-mouths, of a pleasant afternoon, to munch his berries—his wife, that accomplished lady, squatting by his side: his name I never heard, but he is often

described as Probably Arboreal, which may serve for recognition. Each has his own tree of ancestors, but at the top of all sits Probably Arboreal; in all our veins there run some minims of his old, wild tree-top blood; our civilized nerves still tingle with his rude terrors and pleasures; and to that which would have moved our common ancestors, all must obediently thrill."

The leading features of the skeleton in Monkeys and Apes having reference to climbing may be seen in fig. 782, which represents the skeleton of a Gorilla. Besides some of the points which have already been considered, we note in the fore-limb that the collar-bones are well-developed, propping up the shoulder-joints from the inner side, and facilitating lateral movement. The ball-and-socket joint at the shoulder permits, as in a human being, of extensive circular motion. The two bones of the fore-arm (radius and ulna) are both well developed, and the one on the thumb side (radius), which bears the hand, can be turned over the other one, carrying the hand with it, and bringing the back of this uppermost. This *prone* position is shown in the left arm of the figure, and it will be seen that radius and ulna cross one another. The right arm has been placed in the *supine* position, with palm uppermost, when these two bones are parallel. You can note both positions and verify the above facts in your own forearm by rotating it at the elbow. Both of the bones in the lower leg (tibia and fibula) are large, and a certain amount of inward twisting from the knee downwards can be effected, the movement being similar in kind to that taking place in the forearm, though its extent is much more limited. In a Man's leg only one of these two bones is large, *i.e.* the one on the great toe side (tibia), and very little inward twisting is possible.

The hands of the African Thumbless Monkeys (species of *Colobus*) are grasping organs of different character from those so far described. For, as their popular name implies, they have lost their thumbs, or, at most, these digits are represented by small vestiges. But the fingers are long and slender, and the hand can be bent round so as to form an efficient grasping hook. The great toe is well developed and opposable. A species of these Monkeys, the Guereza (*Colobus guereza*), native to North-east Africa is represented in fig. 783.

In Gibbons, the smallest of the man-like apes, and perhaps the most expert climbers of all the Old World Primates, the

arms are exceedingly long, and the thumb very much shorter than the greatly elongated fingers. Indeed these animals use their hands for grasping boughs more as in the Thumbless Monkeys than as in the average Old World forms.

Fig. 783.—Guereza (*Colobus guereza*). Note reduced thumb on right hand

In the American Monkeys we find that the foot is used as a grasping organ much as in the Old World Monkeys, but the hand is employed more after the fashion already described for Thumbless Monkeys and Gibbons (fig. 709). It is true that a thumb is often present, and capable of considerable movement, but it cannot be called opposable. Many of these New World

WEEPER SAPAJOU OR CAPUCHIN MONKEYS
(*Cebus Capucinus*)

The extensive forests of South America are tenanted by a great many animal forms more or less specialized in relation to the climbing habit, and among these none are more characteristic than certain monkeys possessing prehensile tails. The Weeper Capuchin represented in the plate is a common and widely distributed Brazilian species, which is so well adapted to an arboreal life that it but rarely leaves the trees, except for the purpose of drinking. The wrinkled flesh-coloured forehead is very characteristic, and so is the dark patch of fur on the top of the head, which looks like a skull-cap, or close-fitting cowl, and has suggested the name "Capuchin" Monkey. The plate, representing a friendly scrimmage between two individuals, is designed to show the use of the tail. This organ is entirely covered with fur, and is not so much specialized as in the Spider Monkeys, South American forms in which its under side is bare near the tip, in the interests of touch.

WEEPER SAPAJOU OR CAPUCHIN MONKEYS (CEBUS CAPUCINUS)

forms have developed a new climbing organ, for the long tail is frequently prehensile, *i.e.* its tip can be coiled round a branch so as to give a very firm hold. Charles Waterton, the well-known naturalist-traveller, gives (in *Wanderings in South America*) the following graphic account of the way in which this organ is used by a Spider-Monkey:—"This prehensile tail is a most curious thing. It has been denominated, very appropriately, a fifth hand. It is of manifest advantage to the animal either when sitting

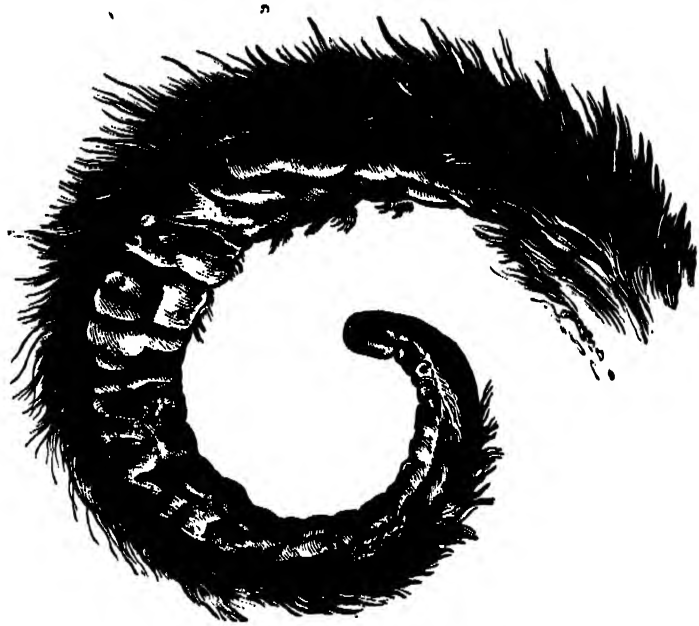


Fig. 784.—End of Tail of a Spider-Monkey

in repose on the branch of a tree, or when in its journey onwards in the gloomy recesses of the wilderness. You may see this monkey catching hold of the branches with its hands, and at the same moment twisting its tail round one of them, as if in want of additional support; and this prehensile tail is sufficiently strong to hold the animal in its place, even when all its four limbs are detached from the tree, so that it can swing to and fro and amuse itself solely through the instrumentality of its prehensile tail, which, by the way, would be of no manner of use to it did accident or misfortune force the monkey to take up a temporary abode on the ground. For several inches from the extremity, by nature and by constant use, this tail has assumed somewhat

the appearance of the inside of a man's finger, being entirely denuded of hair or fur beneath, but not so on the upper part."

Spider-Monkeys (fig. 799), to one of which the preceding extract applies, are slender, long-armed creatures which may be looked upon as the most notable climbers among the New World Monkeys. The under side of the prehensile tail, near its tip (fig. 784), has had its covering of hair suppressed in the interests of greater efficiency, for it is clear that a grasping organ cannot perform its work to best advantage unless it is very sensitive to contact, and the presence of dense fur would no doubt interfere with the sense of touch. And if we are justified in calling the Spider-Monkey's tail a fifth hand, we may also say that its end constitutes an extra finger-tip, which enables the animal to discover branches, &c., which will serve as a tail-hold.

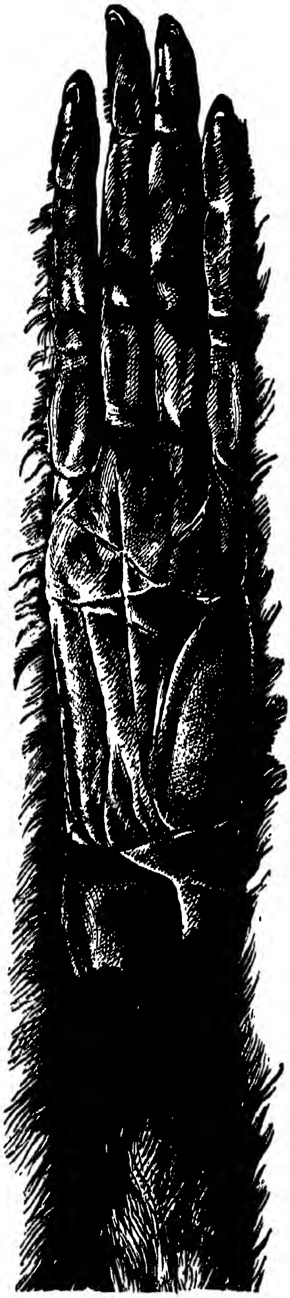


Fig. 785.—Thumbless Hand of a Spider-Monkey

The thumb of a Spider-Monkey is entirely absent, while the fingers and palm are of extraordinary length (fig. 785), and the hand is used hook-fashion, much as in the Thumbless Monkeys of the Old World. Even when a New World Monkey is provided with a thumb it employs its hands in a similar fashion, as will be seen from fig. 786, which represents the hand of a Black Saki (*Pithecia satanas*) grasping a branch. The Sakis have large bushy tails which are not prehensile.

Lemurs (Lemuroidea) as Climbers.—These curious Mammals are native to the warmer parts of Africa and Asia,

while they are particularly abundant in Madagascar. Being specialized climbers of eminently arboreal habit, some of them superficially resemble monkeys, with which they are often confounded, but their structure proves them to be decidedly lower in the

Fig. 786.—Hand of Black Saki (*Pithecia satanas*)

Fig. 787.—Hand of a Brown Lemur (*Lemur brunneus*), showing short but well-developed thumb

scale. Both thumb and great toe are markedly opposable, and the tail is often well developed, but is never converted into a grasping organ. In average Lemurs all the fingers and toes

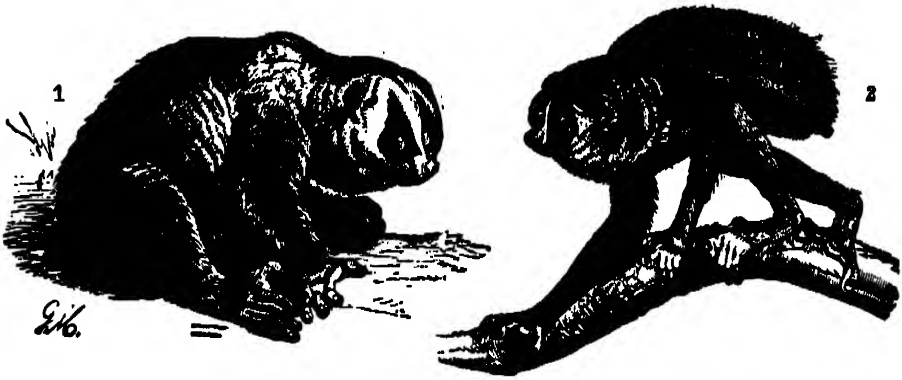


Fig. 788.—1, Common Loris (*Nycticebus tardigradus*); 2, Slender Loris (*Loris gracilis*)

are well developed, and fig. 787 shows the formation of the hand in such a form. In some Lemurs there is a tuft of stiff hairs on the inner side of the forearm, ministering, no doubt, to the sense of touch, and playing much the same part as the sensitive tip of

a Spider-Monkey's tail. A similar arrangement has been described in the Cat, Leopard, Squirrel, and several Pouched Mammals.

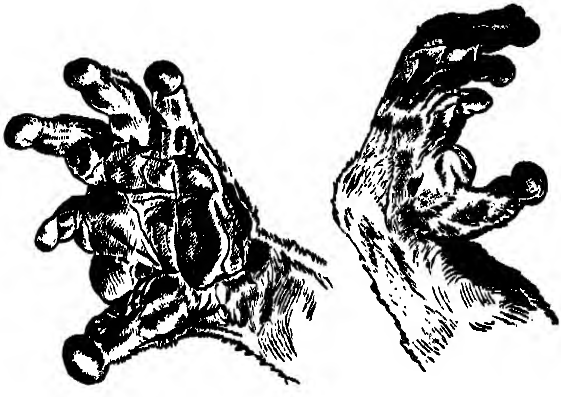


Fig. 789.—Hand of Common Loris (*Nycticebus tardigradus*), showing large thumb and reduced fore finger

In the curious little Slow Lemurs of Africa and Asia, so named on account of the deliberate way in which they move about, the forefinger and its equivalent in the foot have undergone a large amount of reduction. The Asiatic members of the group are known as Loris (fig. 788), and of the two species represented, one, the Common Loris (*Nycticebus tardigradus*), is a clumsy-looking animal, comparable in size to an ordinary cat, while the other is the Slender Loris (*Loris gracilis*), a much smaller animal, with disproportionately small body. The structure of the extremities is much the same in the two cases, and may be illustrated by reference to the former species. We notice that in the hand (fig. 789) the forefinger is much reduced, while the large thumb is opposed to the remaining fingers so as to constitute a grasping organ of unusual holding-power. Much the same is true of the foot (fig. 790), but the reduced second toe is provided with a claw. Both of these Lemurs are practically tailless.

Fig. 790.—Foot of Common Loris (*Nycticebus tardigradus*), showing large first or great toe, and clawed second toe

The Slow Lemurs of Africa (fig. 791) are almost as remarkable in appearance as their Asiatic cousins, and are modified in a similar way so as to enable them to grip firmly to the branches. The two species represented are the only ones known to science,

and both are natives of West Africa. The commoner of the two, which is distinguished by the possession of a short tail, is Bosman's Potto (*Perodicticus potto*), and the other is the Bear-Lemur (*Arctocebus Calabarensis*). The hands and feet of these creatures are constructed on much the same plan as those of the Loris, but the bases of the digits, with the exception of the great toe, are united together by folds of skin, which would appear to give additional firmness to the grip. Haacke (in *Der Schöpfung*

Fig. 791.—1, Bosman's Potto (*Perodicticus potto*); 2, Bear-Lemur (*Arctocebus Calabarensis*)

der Tierwelt) makes the following interesting remarks regarding adaptation of structure to habit in Slow Lemurs:—"To this group belong the Common Loris, the Slender Loris, the Potto, and the Bear-Lemur. In these four species, each of which belongs to a distinct genus, the arms and legs are of approximately equal length. In harmony with this is the reduction of the tail, which is almost absent in the Loris, very short in the Potto, and a mere stump in the Bear-Lemur. The build of the body in these creatures harmonizes with the character of their movements, for none of them are active leapers, like most Lemurs, but when night falls steal noiselessly through the foliage with slow but certain steps, with the object of catching insects, picking fruits,

Specializations of quite another kind are found in the little Spectre Tarsier (*Tarsius spectrum*, fig. 792), an animal of the size of a small rat, native to the East Indies and Philippines, and remarkable among Lemurs for its bizarre appearance. That it is possessed of considerable powers of leaping might be at once inferred from the disproportionate length of the hind-limbs, especially as to the ankle-region, and the great length of the tail, both characters being strongly reminiscent of the proportions in a Jerboa (see p. 196). And this is, in fact, the case, for it leaps with great activity among the branches of trees in pursuit of insects and small reptiles. Its nocturnal habits are evidenced by the extraordinary size of the eyes. Its most remarkable peculiarity, however, is found in the broad adhesive discs in which the fingers and toes end, and the purpose of which is no doubt to obtain a firm hold upon the bark.

Fig. 792.—Spectre Tarsier (*Tarsius spectrum*)

Bats (Chiroptera) as Climbers.—When Bats are not flying about they usually settle on trees or masonry, a safer procedure than coming down to the ground, and under these circumstances they are able to climb about with greater facility than might be expected in creatures with such specialized fore-limbs. This is rendered possible by the existence of strong hooked claws on

the toes, and a particularly strong claw of similar kind on the projecting thumb, in addition to which the large Fruit-Bats have a weaker claw on the forefinger. Many visitors to the Zoo must have noticed with interest the ease with which these particular bats clamber about the bars of their cage. Tickell (in *The Calcutta Journal of Natural History*) thus describes the movements of this sort which he observed in the Fruit-Bat or Kalong (*Pteropus edulis*) in its native haunts when settling down for the day among trees:—"From the arrival of the first comer until the sun is high above the horizon, a scene of incessant wrangling and contention is enacted among them, as each endeavours to secure a higher or better place, or to eject a neighbour from too close vicinage. In these struggles the bats hook themselves along the branches, scrambling about hand-over-hand with some speed, biting each other severely, striking out with the long claw of the thumb, shrieking and cackling without intermission. Each new arrival is compelled to fly several times round the tree, being threatened from all points, and when he

1. 2. 3. 4.

Fig. 793.—1 and 2, Incomplete Suckers on Foot and Hand of a Bat (*Vesperugo pachypus*). 3 and 4, Well-formed Suckers on Hand and Foot of another Bat (*Thyroptera tricolor*)

eventually hooks on he has to go through a series of combats, and be probably ejected two or three times, before he makes good his tenure." The hook-like claws also enable bats to hang themselves up during sleep or hibernation, usually head downwards. Some Bats possess more or less well-developed suckers on the hands and feet, augmenting their clinging powers (fig. 793).

Insect-eating Mammals (Insectivora) as Climbers.—This widely distributed order of rather primitive animals includes members adapted to almost every kind of life, and many of these we have already had occasion to consider in various connections. There

are typical ground forms, such as Hedgehogs, aquatic Desmans, leaping Elephant-Shrews, and burrowing Moles. But this does not exhaust the possibilities, for the Banxrings or Tree-Shrews (*Tupaiidæ*) are typical arboreal Mammals, native to South and and South-east Asia, and much resembling squirrels in appear-

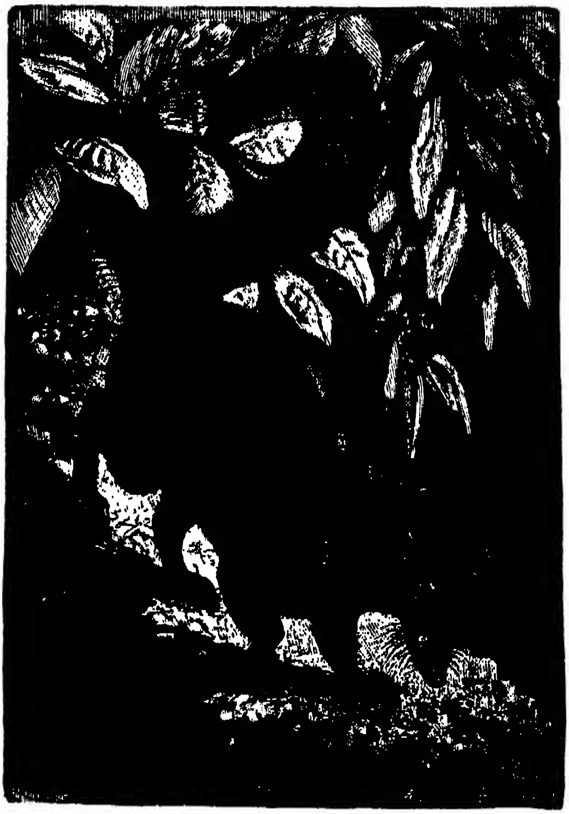


Fig. 794.—Bornean Tree-Shrew (*Tupaia tana*)

ance and movements. The largest species is the Bornean Tree-Shrew (*Tupaia tana*, fig. 794), and it will be seen from the illustration that, in spite of the bushy tail, this animal is decidedly unsquirrel-like as to the snout, which is long and pointed, after the manner of its kind. And examination of the front teeth would at once show the absence of the chisel-shaped incisors so characteristic of squirrels and other gnawing Mammals. The resemblance between these two sorts of climbing Mammal is generally supposed to be a case of "mimicry", the comparatively slow Tree-Shrew benefiting by the resemblance to the more

nimble squirrels. But, curiously enough, there is at least one Squirrel (*Sciurus laticaudatus*) in this region of the world which has acquired a long snout and thus has come to resemble a Tree-Shrew, though the advantage to be derived from this is far from clear.

The adaptations to climbing present in a Banxring chiefly consist in sharp, curved claws, a large tail useful in balancing, and a relatively rather greater development of the hind-limbs, though the last feature has more to do with leaping about among branches than actual climbing.

Flesh-eating Mammals (Carnivora) as Climbers.—With the exception of the Lion most of the members of the Cat Family (*Felidæ*) are more or less expert climbers, *e.g.* Leopard, Puma, and Jaguar. Even Tigers have been known to climb low trees. The facility with which an ordinary cat ascends walls and trees is a matter of common observation. The large amount of lateral movement which is possible in these cases, largely as a result of adaptation to the seizing of prey, is obviously favourable to climbing, and the sharp curved claws are able to render valuable service as grappling-hooks, though this does not appear to have been the primary object of their evolution.

Many other Carnivores are climbers, as, *e.g.*, Bears, Civet-Cats, Martens, and Skunks, but it would hardly repay us to consider them in detail in this connection. The family of the Small Bears (*Sub-Ursidæ*), including Raccoons, Coatis, &c., is much more interesting. With one exception they are natives of the New World, and are particularly abundant in Central and South America. The toes are furnished with sharp, curved claws, which are partially retractile, and the large, often bushy, tail, present as a balancing organ in so many arboreal forms is noteworthy. The Common Raccoon (*Procyon lotor*) (see vol. i, p. 95) of North America is distinguished by the mobility of its fingers, which fits the hands for climbing as well as for various other purposes. But in many ways the most specialized and most interesting member of the family is the Kinkajou or Honey-Bear (*Cercoleptes caudivolvulus*, fig. 799), which ranges from Central Mexico to the River Amazon, and is a notable climber. The feature of greatest interest in this animal is the long prehensile tail, though this is not so specialized as the corresponding organ of a Spider-Monkey, as it is devoid of the bare patch of skin

which in the latter is of importance in connection with the sense of touch (see p. 239). But the fur is "parted" in a curious way so as to expose the surface of the skin to some extent.

Hoofed Mammals (Ungulata) as Climbers.—We have so far been concerned with Mammals which are distinguished by the power of climbing trees, a habit which we should scarcely expect to find exemplified by the members of the present order, although a case has elsewhere been described of an Antelope that is able to ascend branches of some height for the purpose of feeding (see vol. ii, p. 169). But there are numerous Ungulates which climb steep slopes and rocky crags with extraordinary ease. Many of the cloven-footed forms are remarkable in this respect, especially wild Sheep and Goats, some Antelopes, and the Vicunias of South America, which are related to the Camels of the Old World. It is obvious that the split feet of these creatures, and the pointed shape of the hoofs, are well suited for giving a firm hold; and probably this type of extremity has been evolved in relation to clambering up precipitous places that furnished a secure refuge from carnivorous forms. A typical example of these rock-dwelling forms is the Grecian Ibex or Bezoar Goat (*Capra ægagrus*, fig. 795), which ranges from Crete to North-west India, and is probably the "goat" mentioned in Homer. Special interest of another kind attaches to this species, for it is probably the chief stock from which domesticated goats have descended. A wild Sheep, of which the habits are similar to those of the Grecian Ibex, is the Argali (*Ovis argali*), of which mention has been made in another place (see p. 186). The well-known Chamois (*Rupicapra tragus*) (see vol. ii, p. 365) may be taken as an example of a mountain Antelope.

The cloven feet of those even-toed Ungulates which do not chew the cud can on occasion be used for climbing up steep or slippery places, and this is particularly true of the Hippopotamus, which is thus able to ascend river-banks or clamber on to mud-banks without difficulty, in spite of its great bulk (see p. 148).

Conies or Rock-Badgers (Hyracoidea) as Climbers.—These curious little rabbit-like creatures present so many points of resemblance to the Hoofed Mammals that they are often classified with them. All the species are pretty much alike, which makes it at first sight rather surprising that though most of them live in rocky places, others make their homes in trees. It

appears, however, that their spreading feet are well suited for climbing in both kinds of habitat. Vogt (in *The Mammalia*) thus describes the structure and mode of action of the feet of rock-dwelling Conies:—"The weak and short feet have four toes in front and three behind, and these toes are united down to their extremities by skin, and are covered with small, slightly-arched hoofs,

Fig. 795.—Grecian Ibex (*Capra ægagrus*)

with the exception of the inner toe of the hind-foot, which carries a small claw. The sole of the foot is covered with a firm, rough, naked skin, divided into several lobes by means of deep furrows. The Hyracoidea can make use of these little cushions and furrows for the production of vacua which act as suckers. In this manner they cling to the smooth surfaces of the rocks, in the clefts of which they have their retreats. They climb just as easily as geckos, and attach themselves like tree-frogs to smooth surfaces." The arrangement described is equally suitable for tree-climbing.

The species figured is a Tree-Cony or Tree-Hyrax (*Procavia* or *Dendrohyrax arborea*, fig. 796), native to East and South-east Africa. One of the rock-dwelling forms, the Abyssinian Cony or Hyrax (*Procavia* or *Hyrax Abyssinica*), has been figured in an earlier section of this work (vol. i, p. 104).

Gnawing Mammals (Rodentia) as Climbers.—It has been well remarked that the present order and that of the Insectivores

Fig. 796.—Tree-Hyrax (*Procavia arborea*)

resemble one another in the fact that they include members which are severally adapted to almost every kind of life. Nor is this surprising, for both orders are ancient and primitive, and there has been abundant time for them to evolve types able to exploit the supplies of food obtainable in the water, on the ground, under the ground, and above the ground. But whereas the Insectivores mainly subsist on animal food, the Rodents affect a vegetable diet, and the members of the two orders have not therefore competed keenly with one another in the struggle for existence, but have

evolved side by side on the same lines. Some mention has already been made of aquatic Rodents, and of those which run or leap upon the ground, as well as of others which burrow in the soil, and we are here concerned with the climbing members of the order.

Pre-eminent among these are the Squirrels (Sciuridæ), in which the extremities are furnished with sharp curved claws, by

Fig. 797.—Dormice (*Muscardinus avellanarius*)

means of which these animals are able to take advantage of the smallest inequalities of the bark of trees, while the fore-paws can be used pretty much like hands for all sorts of purposes, of which climbing is one. The bushy tail is an important organ for the maintenance of equilibrium under circumstances where acrobatic feats become necessary, and possibly serves other purposes as well (see vol. ii, p. 367).

What is true of Squirrels is also true in the main of the pretty little Dormice (Myoxidæ), although in them the tail is

not so well developed. The accompanying illustration of the Common Dormouse (*Muscardinus avellanarius*, fig. 797) shows very clearly how suitable the extremities are for climbing purposes, and in particular the hand-like character of the fore-paws. It will further be noted that, as in Squirrels (see vol. ii, p. 368), the hind-limbs are relatively long, which is indeed the case with very many arboreal forms, and this is related to the habit of leaping from branch to branch in the search for food, or in retreat from enemies.

In cases where the hind-limbs are the chief agents of progression, it commonly happens that the fore-limbs, being freed

Fig. 798.—Inner side, under surface, and outer side of Left Hand of Cape Jumping-Hare (*Pedetes Caffer*). In left and middle sketches the nearest claw, and in right sketch the furthest claw, is that of the "false thumb"

from the work of supporting the body, are used for other purposes, and become more or less hand-like. Such limbs are frequently of service in climbing, an instance of this being afforded by the Cape Jumping-Hare (*Pedetes Caffer*, see p. 195). This is a specialized leaping form, but with the aid of its hands is able to climb about among rocks with considerable facility. The thumb has been reduced, but the fingers bear strong curved claws, well suited for getting a grip on irregular surfaces. And, curiously enough, a sort of claw-bearing projection has been developed upon the wrist, which may almost be called a "false thumb" (fig. 798).

The Porcupines of the Old World are ground animals, but those of the New World are typically arboreal, the species inhabiting Central and South America reminding us of many

of the monkeys of the same region in the fact that they are possessed of prehensile tails. The Brazilian Tree-Porcupine (*Cercolabes prehensilis*, fig. 799) may be taken as an illustration. As in a Spider-Monkey, the end of the tail presents a bare patch, but this is on the *upper* instead of the under side (see p. 239), in accordance with which the Porcupine coils its tail round a branch in exactly the opposite way to what is the case in the monkey. Thumb and great toe are reduced, while the remaining digits are provided with strong curved claws. The hind-foot possesses an arrangement which reminds one of that found in the fore-foot of the Cape Jumping-Hare, for there is a projection on its inner side which makes up for the absence of the missing toe. This "false great toe" is capable of a certain amount of bending, enabling it to serve as a grasping organ, and its value is enhanced by the fact that the hind-foot is set on obliquely. Both palms and soles are bare and rough on their under sides, this being an adaptation to holding on to the surface of bark. The Brazilian Porcupine and its allies move with great deliberation, suggesting a comparison with sloths. Being plant-eaters, there is no necessity for speed in the search for food, and they rely upon their sharp barbed spines for purposes of defence.

The Canadian Tree-Porcupine or "Urson" (*Erethizon dorsatus*), which is also native to the States, is a larger and clumsier animal, in which the strong tail is non-prehensile, its chief use being as a weapon. In this case, although the thumb has been reduced the great toe is retained. Hart Merriam states that if one of these porcupines "has selected and settled himself in a tree to his liking, he may not leave it, day or night, until he has denuded it of the whole of its foliage. I have seen many hemlocks thus completely stripped, not a green twig remaining even on the smallest bough. It seems incredible that so large and clumsy an animal should be able to climb out far enough on the branches of trees to reach the terminal leaves; but he distributes his weight by bringing several branches together, and then, with his powerful paws, bends back their ends and passes them through his mouth. When high in the tree-tops he is often passed unnoticed, mistaken, if seen at all, for the nest of a crow or hawk."

Mammals Poor in Teeth (Edentata) as Climbers.—The forest-regions of South America are tenanted by a great variety of

animal which have become more or less specialized in relation to climbing (fig. 799), and among these the Sloths are perhaps the most remarkable. The fore-limbs are longer than the hind ones, and remarkably strong curved claws are borne by the digits, of which there are three in the hand and two or three in the foot. A set of climbing hooks is thus constituted, of equal service for suspending the animal from a branch, on the under side of which it is slung without effort, indeed it is said to be able to hang itself up quite comfortably by any one of the four limbs. The upside-down position is habitual, and it is in this position that a Sloth either climbs or walks, according as the particular branch traversed has a considerable or a slight inclination. The movements are deliberate, for the food consists of leaves, and the general appearance and colour harmonize well with the surroundings (see vol. ii, p. 295), so that the eyes of possible enemies are very liable to be deceived. Not only the external characters of a Sloth but also its structure are well adapted to its habits. The backbone possesses an unusual number of vertebræ and is very mobile, which is not only a help in reaching the food, but also enables awkward attitudes to be easily maintained, if they happen for the time being to be convenient. The fore-limbs play a particularly active part in locomotion, and are capable of very free movement: the fore-arm especially being capable of even a larger twisting movement from the elbow than in a human being or a monkey. The digits of the hand (and the same is true of the foot) are not capable of independent movement, being closely bound together by skin. The hind-limbs are constructed on a plan which gives firmness rather than mobility. The hip-bones, for example, are closely united with a considerable length of backbone, and the soles of the feet are kept turned inwards much as in a monkey (see p. 234), but here there is a special arrangement to maintain that position. The two bones of the ankle next the lower leg are, as elsewhere, the heel-bone, and the bone which is remarkable for its pulley-shaped surface in average Mammals, *i.e.* the astragalus. It is the latter which is often called the "knuckle-bone" in the case of a sheep, and furnishes the means of playing a well-known children's game that very likely originated in prehistoric times. In a Sloth the astragalus presents a well-marked smooth surface of peculiar form, for jointing on to

Fig. 799.—South American Mammals with Prehensile Tails

1, A Spider-Monkey (*Ateles Bartletti*). 2, Opossum (*Didelphys marsupialis*). 3, Brazilian Tree-Porcupine (*Cercolabes prehensilis*). 4, Lesser Ant-eater (*Tamandua tetradactyla*) 5, Kinkajou (*Cercoleptes caudivolvulus*).

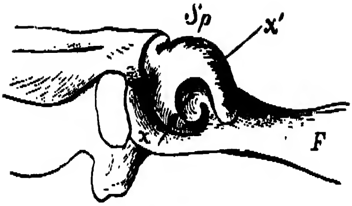


Fig. 800.—Ankle-bones of a Sloth

F, Heel-bone (calcaneum); *Sp*, pulley-bone (astragalus), showing pit for projection of fibula; *x x'*, axis of movement. Base of digits to left.

limited to some extent, and great firmness is given. It may further be noted that in the Three-toed Sloth (*Bradypus*) a great many of the ankle and foot bones are fused together, which obviously contributes to firmness.

Sloths are probably to be regarded as the dwarfed descendants of the large extinct animals known as Ground-Sloths, which formerly existed in South America, and some of which were of huge size, and strong to pull down branches and even fairly large trees for the sake of their leaves.

The Ground-Sloths also appear to be ancestral to the South American Ant-eaters, which have lost their teeth and become adapted to an insect diet. Of these the largest is the Great Ant-eater (*Myrmecophaga jubata*), a ground form which has elsewhere been described (see vol. ii, p. 41). The fore-paws of this creature are provided with strong curved digging claws, for scratching open ant-hills, &c. But since trees furnish a happy hunting-ground for insect-eating animals, it is not surprising to find that some of the Ant-eaters have taken to an arboreal life, their strong claws serving admirably as climbing-hooks. One of these is the Lesser Ant-eater, or Tamandua (*Tamandua tetradactyla*, fig. 799), which is not unlike its larger relative in appearance, except that it possesses a prehensile tail that is constantly used during climbing.

A far more specialized arboreal species is the Two-toed Ant-eater (*Cyclothurus didactylus*, fig. 801), a creature about the size of a rat, native to the hotter parts of America. Were it not for the presence of a long, markedly prehensile tail, it might be taken for a diminutive sloth, for its general appearance and mode of progression are very similar. The snout is rounded instead of being slender as in the Tamandua, while hands and feet bare long hooked claws, to the number of two and four respectively.

Some of the Pangolins among the Old World Edentates (see vol. i, p. 138) climb by means of their sharp claws; and the overlapping scales, of which the pointed ends project backwardly, also appear to help as scaling-irons. This is only true, of course, of the lateral ones, especially those on the side of the

Fig. 801.—Two-toed Ant-eater (*Cyclothurus didactylus*)

tail, and a Pangolin is said to be able to hold on quite easily to the bark of a vertical tree-trunk by means of this organ and the hind-paws, and even to be able under such circumstances to allow the front part of its body to bend outwards at a considerable angle. It is then liable to be mistaken for a short rugged branch abruptly broken off.

Pouched Mammals (Marsupialia) as Climbers.—Tree-Kangaroos, Phalangers, and Opossums, all typical climbing forms, represent the arboreal members of this primitive and multifarious order. The Tree-Kangaroos (species of *Dendrolagus*) inhabit

forest-regions in New Guinea and North Queensland. Just as Sloths and the smaller Ant-eaters of South America are the descendants of ground-forms, so are these creatures an offshoot from the main kangaroo group, of which the typical members are leapers of grazing habit. And in most respects they conform pretty closely to the appearance and structure of their immediate relatives, except that the hind-limbs are not of the same disproportionate length. We have seen, when dealing with the Spectre Tarsier (see p. 244), that leaping powers may be possessed by arboreal forms, and Tree-Kangaroos furnish an illustration of this, as might be expected. Of the movements of the Queensland species (*Dendrolagus Lumholtzii*) Semon speaks as follows (in *In the Australian Bush*):—"It seems very singular that a creature, the structure of which marks it out as a leaping animal adapted to life in the plains, should have accommodated itself relatively well to an arboreal life among trees and leaves, without really changing its character. It must be admitted that its movements among the trees differ somewhat from those of other tree-animals. It jumps upon a low tree at one leap, and thence ascends higher up, always moving by hops and leaps. But it can also climb the higher trees quite deftly by catching hold of the branches with the sharp claws of its fore-feet and applying its hind-feet tightly to the trunk. Arrived in the crown of the tree, it moves about in the same hopping manner; and I was told that it presents a very queer sight jumping about in the foliage of the native woods."

Phalangers constitute another group of climbing pouched Mammals, the members of which usually possess a long prehensile tail, the end of which is more or less destitute of hair, by which the sensitiveness is increased, as in a Spider-Monkey (see p. 239). There are five clawed digits on the hand, and the same number of toes on the foot, all of these being claw-bearing, except the great toe. There are one or two points in the structure of the hind-limb which are specially interesting. The two bones of the lower leg, tibia and fibula, are complete, and the former can be twisted round to some extent, carrying the foot with it, and thus enabling the sole to be turned inwards, a great accommodation in climbing. A similar arrangement has already been described for monkeys (see p. 237). The great toe is very large, devoid of claw, and opposable to the other

toes, an admirable grasping organ being thus constituted as in monkeys. The second and third digits are relatively small, and bound together by a fold of skin, precisely as in a Kangaroo (fig. 802). A typical species, the Common Phalanger (*Trichosurus vulpeculus*) is represented in fig. 802. It is native to both Australia and Tasmania. The smallest and most elegant

Fig. 802.—Common Phalanger (*Trichosurus vulpeculus*)

member of the group, the Long-snouted Phalanger (*Tarsipes rostratus*), has already been spoken of in another connection (vol. ii, p. 181). The Koala or Pouched-Bear (*Phascolarctos cinereus*), on the other hand, is the clumsiest-looking Phalanger, and differs considerably from its congeners (see vol. ii, p. 180). The tail is reduced to a mere vestige, but the absence of this aid to climbing is fully made up for by the unique structure of the fore-foot. For the thumb and first finger together can be

opposed to the other three fingers, and thus the hand is converted into a gripping organ fully as efficient as the clasping foot.

The Opossums of America, almost without exception, are expert climbers, and the general character of average species will be realized by reference to fig. 803, which represents the Common Opossum (*Didelphys Virginiana*). It is about the size of a cat, and much larger than any other member of the same family. The geographical range is considerable, for it is common

Fig. 803.—Virginian Opossum (*Didelphys Virginiana*)

throughout temperate North America, and its area of distribution stretches southwards into tropical South America. No other pouched Mammal is found in the northern half of the New World. The long, scaly, prehensile tail is one of the most striking features of its organization, and the foot is constructed on the same plan as that of a Phalanger, except that the second and third toes are neither reduced in size nor bound together by skin.

Some other pouched Mammals are arboreal, but the most interesting climbing adaptations in the order have now been described.

Birds (Aves) as Climbers.—So much space has been devoted to Climbing Mammals that it will be impossible to attempt anything like a detailed account of Birds adapted to the same habit. Besides, the purpose here kept in view will be sufficiently served by indicating the chief directions along which climbing specializations have been evolved. To these very great interest attaches, for it is reasonable to suppose that the remote ancestors of Birds first forsook life on the ground to dwell among trees, before conquering the realms of air, their proudest achievement.

Many Birds which obtain part or most of their food among trees, either in the form of buds, fruits, and seeds, or as insects and other small animals, have no need to be specialized for climbing. Their power of flight enables them to flit from branch to branch and levy toll on the abundant food-supplies that are thus to be easily reached. Many such forms also roost among the branches at night. It is therefore necessary that the feet should be constructed in such a way as to have a certain amount of grasping power, more especially as it is upon small branches and twigs that most food is to be found, and which also afford the securest sleeping-places. But these small branches at the same time furnish the scantiest foothold, and therefore require to be firmly gripped. As illustrating adaptation to this end the feet of ordinary Perching Birds (Passeres) merit special consideration. Some of the chief facts are easily verified by noticing the way in which tame Canaries, and most of the other small singing-birds kept in captivity, hold on to their perches. As in all Birds, the outer or little toe has been lost, and of the four which remain, the thumb, or inner toe, is backwardly directed. By means of flexor muscles all the digits can be bent, and the opposition of the thumb to the other three toes gives a very perfect grasping organ. The amount of bending is proportionate to the size of the twig upon which the bird has settled. The way in which the feet clasp small twigs is illustrated by fig. 804, in which two Titmice are drawn in different positions. There is an interesting arrangement enabling a bird which perches or roosts upon a small branch to hold on quite firmly without having to use muscular force at all. Two of the muscles

which bend the toes are attached to the toe-bones by fibrous cords or tendons, of which one runs to the great toe, and the other divides into three branches for the three other toes. The weight of the body bends the leg at the ankle, and this pulls upon the tendons, as a result of which the toes are bent. It

Fig. 804.—Long-tailed Titmice (*Acredula caudata*)

is obvious that this "perching mechanism" greatly simplifies the task of grasping a twig firmly during resting or feeding, and it is so perfect that the bird can sleep in safety without any fear of falling. Everyone has noticed tame birds sleeping profoundly upon apparently perilous perches, and no doubt the question "How is it done?" has arisen in the minds of some. The answer has just been given, of course without going into minute anatomical detail. An equivalent mechanism is said to

exist in some of the specialized climbing Mammals, such as squirrels.

Since the fore-limbs of birds have been transformed into wings, it is obvious that the feet must serve as the chief climbing organs, although these are often supplemented by beak and tail. And we are now prepared to understand the structure of "climbing" (*zygodactylous*) feet. Much importance was formerly attached to this in classification, and the pre-eminent climbers among birds, possessing a particular type of such feet were

Fig. 805.—1, Imperfect Climbing Foot of African Plantain-Eater (*Corythaix leucotis*). 2, Specialized Climbing Foot of a Green Woodpecker (*Gecinus*).

lumped together into the group of CLIMBING BIRDS or SCANSORES, including Woodpeckers, Cuckoos, Parrots, &c. The peculiarity of the foot in question consists in the fact that not only the first toe is backwardly directed, but also the fourth or outer one (fig. 805). The sharp curved claws are another characteristic feature. The foot of an African Plantain-Eater (*Corythaix leucotis*) is also represented in the same figure, to illustrate a stage in the evolution of the climbing foot. In this case the outer toe can be turned back when required, but is not permanently fixed in that position. The ordinary perching foot is such a very perfect grasping organ that the climbing foot can scarcely have been evolved in relation to life among small branches and twigs, as under such conditions it would hardly be necessary. But these parts of a tree do not constitute the entire

arboreal larder. The trunk, and branches too large to be encircled by a bird's foot, offer an abundant food supply, for numerous insects and other small creatures are to be found on their surface, and in the numerous small crannies and chinks which are present. And there are many insect larvæ which burrow in bark and wood, from which some birds are able to dig them out. It is clear that the climbing foot is better suited for clinging firmly to a tree-trunk than the ordinary perching foot; for the weight of the body has to be supported, and is mainly borne by the hinder part of the foot, so that two toes turned back are better than one. The ordinary perching foot can, however, be used for climbing up tree-trunks and walls, and clinging to these while food is being collected. A good example is that of the Common Creeper (*Certhia familiaris*), and here the stiff tail is of the greatest use in helping to support the body, thus aiding the great toe (see vol. ii. p. 59). The Nut-Hatch (*Sitta cæsia*) is a closely-related form which is able to cling to the smallest surface irregularities.

The *Woodpeckers* (Picidæ), which with their powerful bills chip out their food from bark and wood, and also excavate deep nesting-places in tree-trunks, possess powerful climbing feet, which cling so closely to the bark that Bowdler Sharpe remarks (in *The Royal Natural History*):—"The tenacity with which the claws grasp the bark of a tree is often illustrated even in death, for sometimes a woodpecker, when fatally wounded by shot, automatically grips the trunk with such vigour as to remain suspended". In most cases the short, stiffened tail also helps to support the body, as in a Creeper, the hard tips of the quill-axes being almost spiny in character. There are, however, some small Woodpeckers known as Piculets, native to both Old and New Worlds, in which the tail is quite short.

After what has been said about the advantages of the four-toed climbing foot, it seems rather curious to find that *Three*-toed Woodpeckers are known which have lost the great toe, but are notwithstanding as expert climbers as the ordinary species. But a plausible explanation of this seems possible. For of the two toes of the climbing foot which are turned back, the great toe is decidedly less useful, since it is not so firmly attached to the shank-bone as the fourth toe. And examination of the foot of an ordinary Woodpecker (fig. 805) will show that the great toe is a good deal smaller that the one which shares its work. From

this we may gather that the great toe, with its comparatively loose attachment to the shank-bone, did not in the first instance prove a strong enough support. This led to its reinforcement by the fourth or outer toe, which became backwardly directed. The said toe, being well developed and having a firm attach-

Fig. 806.—Skeleton of a Parrot. The limbs of the left side only are represented

ment to the shank, would seem to have become able to do all the supporting work required. Hence the gradual reduction of the less useful great toe, and ultimately, in Three-toed Woodpeckers, its entire suppression.

Parrots (Psittaci) constitute a large order of which the members are for the most part typical climbers. The legs are comparatively short, especially in the shank-region, and terminate in typical climbing feet (fig. 806), which constitute highly perfect

grasping organs. So much is this the case that a Parrot often feeds when standing on one foot, the other being used to hold the food, as most of us have observed in captive specimens. No other birds use their feet for this purpose. The beautiful little Hanging Parrots of South-east Asia find another use for these mobile structures, for they habitually sleep suspended from a branch, to which they hold on by one foot.

In those species where the tail is short and broad, it no doubt helps in climbing, the most striking case being that afforded by the Pigmy Parrots of New Guinea, some of which are not so large as sparrows. In these little creatures the shafts of the tail-quills project at the end, very much as in a Creeper (see p. 264). But the powerful hooked beak of a Parrot is a much more valuable aid to climbing, its usefulness in this respect being enhanced by the fact that its upper half is capable of comparatively free movement.

The gorgeously-coloured *Trogons* (Trogonidæ) of Africa, Asia, and America possess grasping feet which look at first sight like those of Woodpeckers. But the two toes which are turned back are here first and *second* instead of first and *fourth*. This type of foot is termed *heterodactylous*, and the arrangement is to some extent comparable to that which is found in the hand of a Koala (see p. 259).

Still another variation of the climbing foot is found in the little *Colies* or *Mouse-Birds* (Coliidæ) of Africa, for here the first and fourth toes of the slender foot can be turned either forwards or backwards at will. The latter procedure converts the feet into efficient grasping organs. A. H. Evans (in *The Cambridge Natural History*) thus speaks of the habits of these birds:—"Colies frequent forest-districts, especially where the bush is thick; they are active, yet not very shy, and are usually found, except during the breeding season, in flocks of some six to eight individuals. The flight is laboured, with many a quick beat of the wings; but it is direct and fairly rapid, though seldom sustained beyond some neighbouring tree, where the bird may be seen stealing through the foliage, and aiding its creeping movements with its bill. The most peculiar habit, however, is that of climbing with the whole metatarsus [*i.e.* the shank-region next the foot] applied to the branch, a fact which adds greatly to the mouse-like appearance. When roosting, Colies are said to

pack themselves together in masses, and to hang by the feet; rarely are they seen perching or hopping, though they often cling to the boughs with the head downwards." The Long-tailed Coly (*Colius macrurus*) is represented in fig. 807.

Fig. 807.—Long-tailed Coly (*Colius macrurus*)

REPTILES (REPTILIA) AS CLIMBERS.—We need only consider under this heading some of the Lizards (Lacertilia) and certain Snakes (Ophidia).

Lizards (Lacertilia) as Climbers.—Many Lizards, such as the American Iguanas, are arboreal in habit, and the Wall Lizard (*Lacerta muralis*) of the Mediterranean countries climbs

about among masonry, &c. But as in these and most other cases of the sort climbing is simply effected by means of the sharp claws, there is nothing of special interest to detain us.

It is quite otherwise, however, with the little Geckos, which are widely distributed through the warmer parts of the world. For here the fingers and toes are specialized into climbing organs of very peculiar nature, quite unlike anything with which we have so far met. In most species the under sides of the digits are broadened out, and provided with a variously arranged series of transverse overlapping folds (fig. 808). The projecting parts of these are thickly studded with curved climbing bristles, each with its tip swollen into a little knob. These are capable of fitting into the smallest inequalities, and no doubt help considerably in the ascent of even slightly rough surfaces. But when it is remembered that a Gecko can climb with facility up the face of a sheet of glass, it is clear that some sort of adhesive action must come into play, very probably of the "sucker" order, in which a vacuum is created by the pulling out of the central part of a smooth piece of skin applied to an equally smooth surface. Gadow (in *The Cambridge Natural History*) gives the following explanation:—" Many, perhaps the majority of Geckos, have adhesive digits, by means of which some kinds are enabled to climb absolutely smooth and vertical surfaces, for instance, a

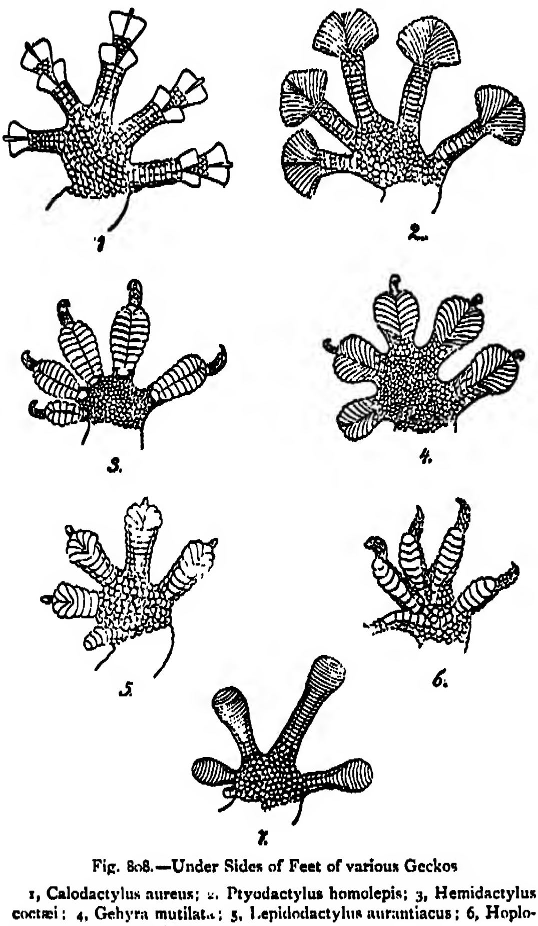


Fig. 808.—Under Sides of Feet of various Geckos

1, Calodactylus aureus; 2, Ptyodactylus homolepis; 3, Hemidactylus coctæi; 4, Gehyra mutilata; 5, Lepidodactylus aurantiacus; 6, Hoplodactylus Anamallensis; 7, Phelsuma Andamanense.

window-pane; or, what is more startling, they run along the smooth whitewashed ceiling, back downwards. The apparatus is complicated in its minute detail, but is very simple in principle. The adhesion is effected by small and numerous vacua. The under surface of each digit is furnished with many trans-

Fig. 809.—Common Chameleon (*Chameleo vulgaris*)

An outer view of the left fore-foot is given above and a similar view of the left hind-foot below.

verse lamellæ. The pressing down of the foot upon a smooth surface causes the lamellæ to spread asunder and drive out the air; partial retraction lets them return to their original position by virtue of their elasticity; and little vacua are produced. Each lamella is further beset with tiny hair-like excrescences, which secure adpression to even the slightest irregularity of surface, and at the same time enhance the elasticity of the pads."

Some of the Lizards possess grasping feet constructed more

or less on a plan of which so many examples have now been given for Mammals and Birds. There is, for instance, a good-sized species (*Lyriocephalus scutatus*) inhabiting Ceylon, in which thumb and great toe are opposable, somewhat as in an Old World Monkey. And this leads up to the much more remarkable case of Chameleons, where by union of the digits into two groups both hands and feet are converted into most efficient grasping organs (fig. 809). The united digits are grouped differently in the two extremities. The thumb is bound up with the two adjoining fingers, and the two other fingers (fourth and fifth) are similarly connected. But the great toe is united only with its neighbour, while the three outer toes (third, fourth, and fifth) are also joined together. The latter arrangement is reminiscent of the hand of a Koala (see p. 259). And as if such climbing hands and feet were not sufficient, the long curly tail is very prehensile.

Snakes (Ophidia) as Climbers.—Many Snakes climb most admirably by writhing round the trunks and branches of trees, a procedure which is rendered possible by the extreme flexibility of their bodies, and the great development of the lateral muscles. The backwardly projecting edges of the ventral shields prevent slipping back, just as in ordinary locomotion on the ground (see p. 110). Pythons and Boas, the largest of existing snakes, climb after this fashion, and their short prehensile tails enable them to hang from a branch on the look-out for prey. Among smaller forms which climb trees more or less in pursuit of food may be mentioned our common Grass Snake (*Tropidonotus natrix*), the Æsculapian Snake (*Coluber longissimus*) of Europe, and the American Black Snake (*Zamenis constrictor*). The Wood-Snakes of the West Indies and the hotter parts of Central and South America are thoroughly arboreal forms, and their dull green colour makes them inconspicuous among the foliage of their native forests. A well-known species is the Brazilian Wood-Snake (*Herpetodryas carinatus*, fig. 810), which may be as much as 7 feet long. Some very interesting Tree-Snakes (species of *Dendrophis* and *Dendrelaphis*) belonging to the Eastern Hemisphere, are distinguished by the conversion of the ventral shields into climbing structures. Each of these scales has a well-marked longitudinal ridge near either side, and the freely projecting back edge possesses a couple of notches corre-

sponding to these. Gadow (in *The Cambridge Natural History*) speaks of these scales as—"arrangements which are of great assistance in climbing, these snakes being able to slide up the

Fig. 810.—Brazilian Wood-Snake (*Herpetodryas carinatus*). The head is drawn on a larger scale above

branches of trees in almost straight lines, instead of having to twist and undulate their way up".

All the preceding forms are non-poisonous. Most of the venomous serpents are ground forms, though to this there are exceptions, and some species which generally live on the ground can climb on occasion. Among typical arboreal forms may be mentioned the slender Whip-Snakes (species of *Dryophis*), native

to India and South-east Asia, and the climbing Tree-Vipers (species of *Trimeresurus*) of India and Burmah. The tails of the latter are prehensile.

AMPHIBIANS (AMPHIBIA) AS CLIMBERS.—The only forms of special interest in this connection are the little Tree-Frogs (*Hylidæ*), which have a wide distribution in both Old and New Worlds. One of the most familiar species is the common little Green Tree-Frog (*Hyla arborea*) of Europe and North Africa, which also ranges eastward to Japan. A novel kind of climbing apparatus is here present, in the form of little adhesive cushions on the under side of the tips of the digits. These appear to act by means of "adhesion", *i.e.* the mutual attraction of two surfaces which are brought into intimate contact. It is probably in the same way that a Limpet (*Patella vulgata*) adheres to its scar (see vol. ii, p. 197). The pad is supported by a gristly disc, and contains muscle-fibres which, by their contraction, help to adjust it to the surface of a twig or leaf. There are also small glands in the skin of the pad, and the slimy secretion poured out by these promotes adhesion by helping in the expulsion of air from between the two surfaces in contact.

FISHES (PISCES) AS CLIMBERS.—There is nothing of very special interest to engage our attention here. Of course such fishes as Eels, which from time to time leave the water, have to do a certain amount of climbing work. The shore-haunting Mud-Skippers (*Periophthalmus*), which have already been spoken of several times, are able to climb boulders and mangrove roots by means of their powerful pectoral fins, which are hooked over projections. It has also been stated that the Climbing Perch (*Anabas scandens*) is able to ascend the trunks of trees by means of the same fins but the statement requires confirmation.

BACKBONELESS ANIMALS (INVERTEBRATA) AS CLIMBERS

We may here instructively consider how climbing is effected by some of the Jointed-Legged Animals (Arthropoda) and Hedgehog-Skinned Animals (Echinodermata).

JOINTED-LIMBED ANIMALS (ARTHROPODA) AS CLIMBERS.—Experts in this sort of locomotion are to be found among Insects (Insecta), Spider-legged Animals (Arachnida), and Crustaceans (Crustacea), and it will be well to remember in both cases that

THE EUROPEAN TREE-FROG (*Hyla arborea*)

This pretty little Tree-Frog has a wide distribution in Europe, from which it ranges east to Japan, and south into North Africa. It is extremely active, and possesses little rounded pads on the tips of its fingers and toes, which are able to adhere firmly even to perfectly smooth surfaces. The upper side of the body is green, shading off into a whitish tint on the under side. A considerable amount of colour-change is possible, enabling the animal to harmonize with different surroundings. By this "variable protective coloration" it often escapes the observation of its enemies; but the arrangement is also an "aggressive" one, helping to conceal the animal from its prey, which consists largely of insects. The male possesses a very large "croaking pouch" on the under side of its throat. This serves as a resonator, and when fully expanded looks something like a football.

THE EUROPEAN TREE-FROG (HYLA ARBOREA)

the limbs employed are quite different in structure from those of Backboned Animals (see p. 163).

Insects (Insecta) as Climbers.—The structure of the limbs in climbing insects depends upon the nature of the surfaces on which progression takes place. These may be either rough or smooth, necessitating two distinct kinds of adaptation, similar to those already exemplified among the backboned forms.

Fig. 811.—Long-horned Oak-Beetle (*Cerambyx heros*)

Undoubtedly the remote ancestors of Insects had numerous pairs of legs, as Peripatus, Centipedes, and Millipedes still have. The reduction to six pairs was very probably an adaptation to climbing (see p. 167), while at the same time the body became shorter and more compact.

Among insects capable of climbing upon a rough surface, such as that presented by bark, are many Tree-Beetles, especially those which are known as "longicorns", on account of the length of their feelers. An insect of this kind is shown in fig. 811, which represents the Long-horned Oak-Beetle (*Cerambyx heros*). The climbing mechanism will be understood by reference to the accompanying outline of a leg of the Cockroach (*Periplaneta orientalis*, fig. 812), an insect which is able to scale walls with undesirable facility. The parts of the leg are, beginning at the top,—hip (coxa), trochanter, thigh (femur), shin (tibia), and foot (tarsus). The last, with which only we are here concerned, is made up of five little joints, and bears a pair of curved claws at its tip. It is these which constitute the holdfasts by which climbing on a

rough surface is rendered possible, and in this respect they are comparable to the claws of a cat or tree-lizard. Similar claws are present on the feet of a great many other insects, such as the beetles above mentioned, cockchafers, tree-grasshoppers, and tree-bugs. From the stand-point of evolution these structures are of very great interest. They are almost certainly to be regarded as an inheritance from the segmented worms, which were the ancestors of Arthropods. These worms, like the recent Bristle-Worms (see p. 98), no doubt had numerous pairs of unjointed foot-stumps, in which bristles were imbedded. There fortunately exists a recent form (*Peripatus*, fig. 813), which, though an undoubted Arthropod, resembles bristle-worms in many respects. Its numerous legs are very like foot-stumps, and each of them bears two sharp claws, which may be looked upon as specialized bristles. And if insects have descended from bristle-bearing worms through ancestors resembling Peripatus, their claws are probably to be explained in the same way.

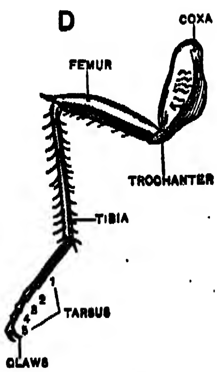
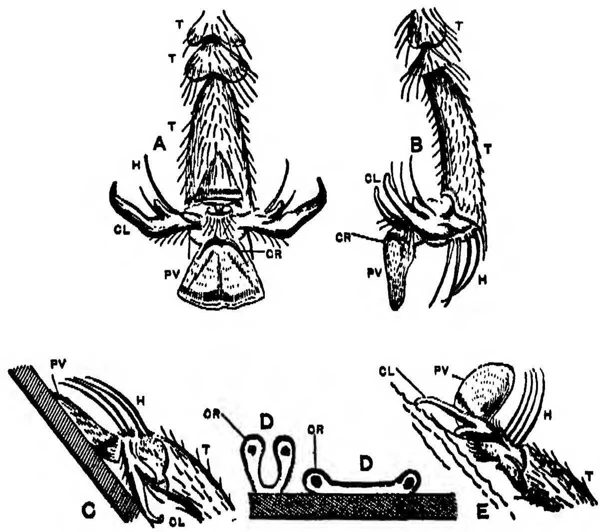


Fig. 812.—Leg of a Cockroach (*Periplaneta orientalis*)

Fig. 813. Cape Peripatus (*Peripatus Capensis*)

Bees are able to climb both rough and smooth surfaces, and their feet are marvels of adaptation to this double power. Not only are two claws present for use as already described, but also an end-flap or *pulvillus*, which comes into action when the insect desires to ascend a smooth surface or to walk upside down in the fashion familiar to us all. The following quotation and the accompanying figures (figs. 814, 815) are taken from Cheshire, who has made a very thorough study of the Honey-Bee in this and other connections. On a rough surface "the points of the claws catch (as at E), and the pulvillus is saved from any contact, but if the surface be smooth, so that the claws get no grip, they slide back and are drawn beneath the foot (as at C), which change of position applies the pulvillus, so that it immediately clings. It is the character of the surface, then, and not the will of the bee, that determines whether claw or pulvillus shall

used in sustaining it. But another contrivance, equally beautiful, remains to be noticed. The pulvillus is carried folded in the middle (as at E), but opens out when applied to a surface; for it has at its upper part an elastic and curved rod (CR), which straightens as the pulvillus is pressed down; C and D (fig. 815) making this clear. The flattened out pulvillus thus holds strongly while pulled, by the weight of the bee, along the surface to which it adheres, but comes up at once if lifted and rolled off from its opposite sides, just as we should pull a postage-stamp an envelope. bee, then, is held securely till it attemps to lift the leg, when it is freed at once; and by this exquisite yet simple plan it can fix and release each foot at least twenty times per second." The pulvillus would appear to act by adhesion, much in the same way as the pads on the toes of a Tree-Frog (see p. 272). Nor does the resemblance cease here, for in the frog there are glands in the skin, which pour out a secretion that enables the air to be expelled from between pad and underlying surface, while in the insect the under side of the pulvillus is studded with holding-bristles from which a similar fluid exudes that answers the same purpose. We further notice the presence of a number of touch-bristles (H) on the end of the foot, and these probably help the insect in the selection of foot-holds. They are reminiscent of the stiff hairs on the wrist of some Lemurs, by which a similar purpose is served (see p. 241).



Figs. 814, 815.—Structure and Action of Foot of Honey-Bee (*Apis mellifica*)

A and B, Under surface and side of foot. C, Foot as used for climbing on smooth surface. D, Cross-sections of pulvillus in partly folded and fully unfolded conditions. E, Foot as used for climbing on rough surface. CL, Claws; CR, elastic rod of pulvillus; H, tactile hairs; PV, pulvillus; T, joints of tarsus.

A favourite microscopic object is the foot of the House-Fly (*Musca domestica*, fig. 816), which is constructed on a similar plan

to that just described for the Bee, and possesses claws and two end-flaps. It is the adhesive power of the latter which enables the insect to walk along a ceiling.

Fig. 816.—Under Surface of Foot of House-Fly (*Musca domestica*), greatly enlarged, showing claws and pulvilli.

It may be as well to state that the explanation of the adhesive power of the insect-foot, as just given, is not the only one possible, nor is it accepted by all zoologists. But it appears to the present writer to be the most plausible so far advanced, at any rate for the special insects named.

Spider-like Animals (Arachnida) as Climbers.—For our present purpose it will be enough to consider the case of web-spiders. The foot, for example, of a Garden Spider (*Epeira diadema*, fig. 817) terminates in three claws. Two of these (*a*), constituting a pair, are the comb-like weaving-claws which have to do with web-construction, and are helped in their work by some saw-edged bristles (*c*) on the under side of the foot. The unpaired third claw (*b*) is strongly hooked, and employed for climbing about the web, or on objects outside it. No doubt the specialized weaving-claws also help the spider to hold on to its snare.

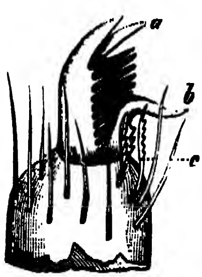


Fig. 817.—Side View of Foot of Spider, greatly enlarged *a*, Weaving-claws; *b*, climbing-claw; *c*, saw-edged weaving-bristles.

Among Spiders which construct no webs it is usual to find only a pair of claws, which play the same part as those on the tip of an insect's foot, and are equivalent to the weaving-claws of the web-spinners. In some species, such as the Harlequin Spider (*Salticus scenicus*), a well-known hunting form, there is a tuft of climbing-bristles on the under side of the foot. Their presence is associated with the power of scaling vertical surfaces and progressing upside down fly-fashion. We are reminded here of the similar structures on the feet of Geckos (see p. 268).

The first pair of legs, immediately behind the head, have sharp end-joints which can be turned back so as to work against the part of the limb to which they are attached. The arrangement is comparable to a hand with one finger capable of being bent round against the palm. The hinder part of the body bears three pairs of legs with curved claws, which materially aid in the climbing movements.

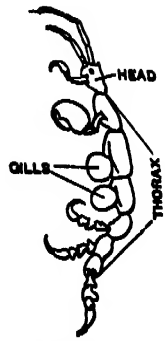


Fig. 818.—Skeleton Shrimp (*Caprella*), enlarged.

The great pincers of a Crab, Crayfish, or Lobster (fig. 819) are grasping organs of more complex nature, which serve many

Fig. 819.—Lobster (*Homarus vulgaris*)

purposes besides climbing. Here we find the smaller jaw of the pincers is the freely movable end-joint. This works against the large preceding joint, which is drawn out into a long toothed projection, constituting the other jaw of the pincers. The large

size of this grasping organ is due to the presence of powerful muscles by which the jaws are opened and closed. In a Lobster or Crayfish the first two pairs of walking-legs terminate in nippers of similar nature, but of comparatively small size.

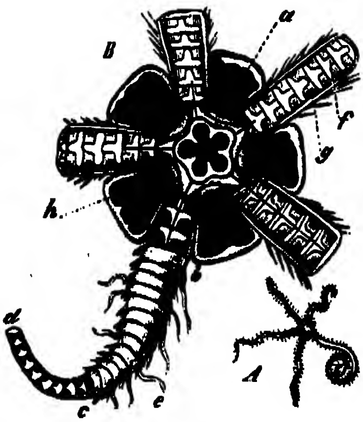
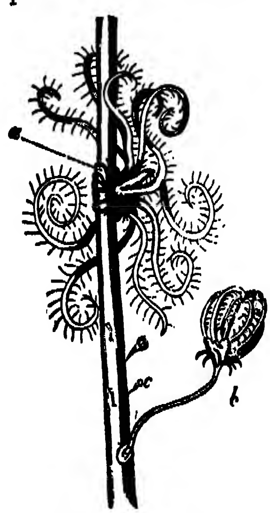
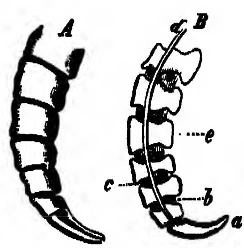


Fig. 820.—Brittle-Star

The flexibility of the arms is illustrated by the small figure A. B is partly dissected from below to show structure: *a*, mouth-plates; *becd*, an arm from which some of the under-plates have not been removed; the other arms have been cut off very short to show central plates (*f*) and their muscles (*g*); *h*, a breathing-pouch cut open.

HEDGEHOG-SKINNED ANIMALS (ECHINODERMATA) AS CLIMBERS.—The *Brittle-Stars* (*Ophiuroidea*) have aptly been called "Echinoderm Monkeys", as many of them are expert climbers. The five arms of an ordinary Star-Fish are merely prolongations of the body in which the digestive organs are partly lodged. But in Brittle-Stars (fig. 820) a sharp distinction can be drawn between a disc-shaped central body and five flexible, jointed arms, which may be looked upon as true limbs or appendages. Each arm is covered by overlapping limy plates, and its interior is mostly filled up by a series of hard pieces jointed together in such a way that all sorts of complicated curving movements can be executed by the agency of appropriate muscles. So





Figs. 821, 822.—A Feather-Star holding on by its Grasping-threads (*a*), and its larvæ (*bc*) attached by stalks. A and B (section) represent terminal part of a grasping-thread; *a*, end claw; *bc*, muscle; *d*, elastic band; *e*, limy joint.

much is this the case, that a parallel has often been drawn between the arm of a Brittle-Star and the sinuous body of a Snake.

The *Feather-Stars*, belonging to another group (*Crinoidea*), of which most members are fixed by long stalks, possess another sort of climbing apparatus (fig. 821). The very young animal is stalked, but soon becomes free, and close to the spot where the stalk was attached a circlet of slender grasping threads is developed. Each of these is made up of a series of limy joints, of which one end serves as a curved claw. The thread can be sharply bent by means of bundles of muscle-fibres which connect the successive joints, and straightened again by the elasticity of a fibrous band that runs through the centre of the thread. A grasping organ is thus constituted, which is almost like the foot of a bird, and may be used simply for fixing the animal to some firm body, or for climbing purposes.

The active Feather-Stars present a marked contrast to their sluggish stalked relatives the Sea-Lilies. But it is easy to understand how the difference between the two types has come about. We know that Sea-Lilies were once a dominant group, and flourished exceedingly in geological epochs very remote from our own times. It would seem that the competition for food among marine animals was much less keen than it is now, and fixed animals like the Sea-Lilies were at no great disadvantage. But as time went on the struggle for existence became more severe, and active rapacious forms such as higher Crustaceans and Fishes made it increasingly difficult for fixed species to maintain themselves. Sea-Lilies gradually diminished in numbers and importance, and the few forms which now exist are comparatively rare, and inhabit the deep sea, which has served as a refuge to them and other hard-pressed forms. But some creatures of the sort evolved along lines which have resulted in the Feather-Stars. These are simply to be regarded as Sea-Lilies which have given up their stalks and taken to an active life, though the larvæ are still stalked, as a sort of memento of the former state of things. That this step has proved successful is sufficiently shown by the great abundance and wide distribution of Feather-Stars at the present day. In very remote times, geologically speaking, Sea-Lilies were not the only stalked Echinoderms, there being two other groups of the kind, both of which have long been entirely extinct. Under present conditions a fixed life is decidedly unfavourable to Echinoderms, though it appears to answer well enough in certain other

groups, *e.g.* Sponges and many Ascidians. Fixed animals are of necessity comparatively helpless, and when this kind of existence is a success there always appear to be effective protective arrangements. Rapid changes in the surroundings are usually unfavourable to highly specialized forms, which are not sufficiently plastic as it were to accommodate themselves with sufficient quickness to new conditions. This is probably why the Sea-Lilies are a declining group, of which, however, the Feather-Stars represent a vigorous branch that is probably able to hold its own for an indefinite time.